THE STRUCTURE OF THE GEOTHERMAL INDUSTRY THROUGH 1974

by

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ABSTRACT

The report is divided into four chapters which deal, respectively, with the technical and institutional conditions that shape geothermal development, the factors that determine the value of a geothermal lease, patterns of bidding for geothermal leases offered by the Federal government, and the emerging structure of the geothermal industry.

The economically most important use of geothermal energy is central station electricity generation. That process is characterized by uncertainty, indivisibilities, and the need for coordinated investment planning between steam developers and power plant owners. The process will be affected by rate regulation of electric utilities and by land-use regulations, especially those affecting Federal lands.

The value of a geothermal lease will be determined by conditions on three markets: the regulated market in which utilities sell electricity, the complex market in which a small number of utilities buy steam from a potentially large number of suppliers, and the market in which suppliers purchase land rights. If all markets were perfectly competitive, a geothermal lease would sell for the capitalized value of the stream of economic rents generated by the resource. Market power held by some participants in those markets could reduce the rents actually accruing to landowners. Based on 1970 cost estimates, estimates are made of the value of a lease at the Geysers under competitive conditions and under actual selling prices of geothermal leases. The values are sensitive to tax laws and to the rate of return required.

Bids on Federal leases are analyzed to find a measure of the amount being paid for geothermal leases at the Geysers, which is compared to the values predicted under different market conditions. Difficulties of interpreting this comparison due to the nature of competitive bidding processes are also discussed. In addition, different patterns of bidding behavior among types of geothermal resource areas and among types of bidders are identified.

In the fourth chapter, some fragmentary data on ownership of geothermal leases are assembled to give a preliminary estimate of concentration ratios in geothermal energy. Factors that could explain the apparently high concentration ratios are suggested.

The final chapter is a summary of conclusions and recommendations for further research.

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INTRODUCTION

In recent years it has become apparent that geothermal energy forms an important, though relatively small, part of the energy resources of the United States. Until now the development of the geothermal resource has been largely in the hands of private industry regulated and affected in numerous other ways by government agencies. In this study of the past and current behavior of the geothermal energy industry, we hope to form a basis in economic analysis for public policy toward geothermal energy. The study focuses on the behavior of private industry in geothermal development in order to begin to provide answers to two classes of questions: 1) What is the effect of tax laws, regulatory decisions, and other governmental actions on geothermal development; and 2) what patterns can we expect to observe in the present and future actions of private industry?

Numerous concerns about these patterns have been expressed in popular and governmental forums. A feature article in the Los Angeles Times expressed what appears to be a widespread fear of the consequences of the domination of the geothermal industry by a few large oil firms, especially in their bidding on Federal geothermal leases.[1] The question of industry structure and its relation to the Federal leasing program will be explored at length in this report.

Problems of regulatory, environmental, and land use policy also arise in regard to geothermal energy. Since a regulated electric utility has a natural place in the development of geothermal energy, regulatory actions in regard to setting electricity rates and rates of return, allowing entry into electricity production, and encouraging the entry of electric utilities into geothermal steam production (vertical integration) can have important consequences. Finally, environmental and land use consequences of geothermal development can only be predicted and controlled if the incentives facing geothermal developers and the net benefits of geothermal development are understood.

To provide a factual basis for conclusions in these areas, we use three types of data: bids on Federal leases by potential geothermal developers, estimates of costs and revenues of geothermal steam production and resulting generation of electricity, and measures of the degree of concentration in the geothermal industry. The study begins with a brief summary of technical and institutional facts useful for understanding the cost of producing electricity from geothermal energy and, especially, for understanding the nature of bids for geothermal leases. In the second chapter we analyze the geothermal energy system in three related markets: a market for land, a market for steam, and a market for electricity. As participants in these markets, we find landowners, geothermal developers, electric utilities, and electricity consumers.

The distribution of the benefits of geothermal energy among the four groups depends on the structure of each of the three markets. Using rates of return on investment by geothermal developers, lease prices, and electricity rates as data, we reach some tentative conclusions about the distribution of these benefits. In the third chapter we analyze bidding for Federal leases. We domonstrate first that there are systematic, explainable patterns in the bids, and from these patterns draw some inferences about the structure and behavior of the geothermal industry. In the fourth chapter we examine well-known measures of concentration and the bidding behavior of oil companies with a view to supporting some general conclusions about the degree of competition in geothermal development. Results are summarized and suggestions are made in a terse final chapter.

Although the study is an avowedly technical one, relying on theoretical arguments to interpret and supplement the data, it is not intended solely for the eyes of economists. Hence, short heuristic recapitulations of major points appear throughout the text. Hopefully, economists will forgive these asides, keeping in mind how unpleasant non-economists find the technical sections.

The study was concluded on June 30, 1975, and does not reflect events subsequent to December 31, 1974. All Federal lease sales held prior to that data have been included in the analysis.

Footnotes

1. George Alexander, "Geothermal Energy: Oil Companies Scramble for Control," Los Angeles Times, Monday, November 11, 1974.

CHAPTER 1

TECHNICAL AND INSTITUTIONAL BACKGROUND

The distinctive features of the geothermal energy industry arise from physical characteristics of the geothermal resource and specific laws and institutional arrangements governing its use. Hence, before proceeding to detailed theoretical and empirical analysis, we will present a brief summary of relevant physical and institutional facts.

1.1 Technical Conditions of Production

Although geothermal resources can be used for many purposes, including mineral extraction and low-level heating, the use which now appears to have the largest potential economic significance is the generation of electricity from geothermal fluid.[1] In order to produce electricity, the geothermal fluid, which can be in a state ranging from superheated steam to hot water, is obtained from wells and transported through pipelines to generating stations. The generating facility required differs with the chemical composition, temperature and pressure of the steam, but in all cases uses turbines which operate at low pressures compared to conventional steam plants, or will use secondary fluid systems.[2] The electricity then must be transmitted to load centers or a distribution grid. The only use of geothermal energy considered in this report will be the generation of electricity.

All over the earth's surface, temperature increases with depth below ground. In certain areas magma from the earth's interior intrudes an unusual distance into the surface layers. When underground water is trapped near the intrusion and the resulting local concentrations of heat, a reservoir of geothermally heated water or steam is created.[3] Those reservoirs accessible to drilling are of potential value as sources of energy. In the United States one such reservoir located in Sonoma County, California, is currently being used to produce electricity on a commercial basis. Our description of actual production practice, as opposed to general production possibilities, will be based largely on operating practice at the Geysers, as this field is known.

The first step in economic use of geothermal energy is the winning of steam. This part of the production process involves large uncertainties in all of its several stages. Geological and geophysical surveys provide evidence of the possible existence of hot water or steam below ground. Exploratory drilling can then, if successful, locate and provide some estimates of the quality of the reservoir. Until pressure, temperature, and chemical composition are ascertained, power generating facilities cannot be designed.[4] The process of estimating the characteristics of the geothermal fluid and the size of the reservoir is known as "proving the reservoir". Even after the reservoir is proved, each new well involves its own uncertainties.

Expansion of output in a field generally requires drilling of additional wells.[5] Each such "step-out well" is of uncertain quality because of two factors: the varying depth of the reservoir and changes in the permeability of rock between known wells and the new well. At the Geysers this uncertainty appears minimal: over 14 years between 1955 and 1969, 69 wells were drilled, and all but four produced economic quantities of steam. In general, however, the quality of the fluid obtained will vary with the location of wells in a field. Moreover, in most cases the boundaries of a field are not themselves known until after extensive testing and sinking of wells.[6]

The geothermal fluid obtained from a successful well varies in characteristics between fields. The Geysers and Lardarello (Italy) fields produce dry steam with few mineral contaminants. Other wells, such as those at Wairakei, New Zealand, produce a mixture of steam and water. In the Imperial Valley of California the mixture also contains high concentrations of minerals which cause serious difficulties in using the steam for power generation. At all fields currently utilized for electricity generation, the fluid flows from the well under its own pressure, although pumping is technically possible.[7]

Most authorities agree that the rate at which the fluid is extracted from a reservoir affects the pressure and temperature of the fluid obtained. Spacing of wells and each well's flow rate, which is a function of well diameter and depth, and the design wellhead pressure determine the rate of extraction.[8] Increased flow rates reduce the pressure of the steam obtained while those flow rates are in effect.

It is believed that individual wells have a finite life, and that production rates drop off with time. Some authorities argue that this decline in production is caused by the depositing of minerals, which eventually close the cracks in underground rock through which the geothermal fluid reaches the well, and that a new well might have the same production rate as did a closed well when new.[9] However, if a single, unreplenished reservoir of water is the source of the fluid, the field will dry up. It should be noted that the expert opinion accepted by a Federal Tax Court in Reich, et al., holds that the reservoir is not replenished and that extraction of a geothermal fluid depletes the reservoir.[10] Since well construction costs currently exceed land acquisition costs by an order of magnitude or more, the general expectation that any well will have a life of twenty years or less is far more important to economic incentives to invest in geothermal development than is the possibility that the resource itself is depleted by use.

The geothermal fluid must be transported from the wellhead to a generating plant in most cases. Although some studies indicate that at some fields it is economic to place a small generator at each well,[11] at any large field it is possible to achieve economies of scale by collecting steam from many wells and using it to drive a single turbine.[12]

Costs of transporting the fluid vary with its characteristics. Superheated dry steam is cheapest to transport. Mixtures of water and steam create technical transport difficulties which raise the cost of pipelines, and fluids with low energy content must be protected against losses in transportation by more expensive pipelines. Corrosive fluids clearly can also increase costs of transportation.[13] For this reason steam and water are generally separated at the wellhead.

Power turbines in geothermal generating plants are driven by steam, which is either obtained directly from wells, as at the Geysers, separated from mixtures of water and steam, or produced from hot water by "flashing". Flashing requires a lowering of pressure to bring the fluid into a vapor phase. Steam can be separated from water, or water flashed to steam, before or after being transported from the well to the generating facility.[14]

Even at the Geysers the pressure of the steam at the power plant is well below the pressures characteristic of power plants using artificially heated steam, whether nuclear or fossil fueled. The first generating facility at the Geysers used the low pressure stage of an obsolete steam turbine owned by Pacific Gas & Electric Company (PG&E).[15]

The low pressure lowers the thermodynamic efficiency of electricity generation below that characteristic of thermal power plants.[16] Hence the "prime mover"* may involve higher capital costs per kilowatt than other types of facility. The higher costs can be offset by savings on the capital cost of steam production with oil or gas fired boilers or a nuclear reactor, and on the the cost of fuel. The low pressures mean that economies of scale in turbine construction are practically exhausted in a 100 MW unit,[17] owing in part to the large exit section required.

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*The "prime mover" is the part of the power plant, such as a turbine that converts the energy of the working fluid, such as steam, into electrical energy.

The construction of generating capacity and drilling of wells must be carefully coordinated in an optimal investment plan, so that unusable steam or idle capacity is avoided. If geothermal fields are depleted through exploitation, coordination between reservoir management and the construction of generating capacity is also necessary to match the life of the field to the life of the power plant. The uncertainty characteristic of drilling in many fields, and an ownership pattern in which one firm produces steam while another firm produces electricity, can make this coordination difficult.

The transmission of electricity produced from geothermal energy differs from transmission of electricity produced in other ways only in the lack of flexibility in locating the power plant. The distance of a field from load centers or existing transmission lines with excess capacity will affect its economic desirability.

After generating electricity, the steam condenses to water containing various impurities which affect the nature and cost of disposal. Moreover, in water fields the separated water, generally high in mineral content, must be disposed of also. The need for reinjection wells can raise the capital cost of geothermal energy.

In summary, there are four separate processes involved in geothermal power production: winning the fluid, transporting the fluid, producing electricity, and transporting electricity. The process of winning the fluid is characterized by uncertainty and indivisibilities. The nature of the reservoir necessitates coordination among steam producers and between those producers and the owners of the generating facility. Because of increasing losses of energy as pipelines become longer, the location of the generating facility affects the value of individual wells as a function of their location. Although the electricity generating process is not characterized by substantial increasing returns to scale, the need to build transmission lines can set a minimum efficient scale for power production.

Electricity can be produced from geothermal steam at a total cost per kilowatt which was estimated in 1973 as 5.3 mills/kwh. The same source estimates total production cost in a coal-fired plant at 8.2 mills/kwh, nuclear at 9.6 mills/kwh, oil-fired at 10.0 mills/kwh, and hydroelectric at 9.6 mills/kwh. In other fields, where mixtures of steam and water are obtained from the wells, production costs with geothermal energy rise, and are estimated at 9.7 mills/kwh.[18] Current estimates of production costs in nuclear power plants run as high as 22 mills/kwh.[19] Since geothermal production costs do not appear to have risen as sharply, we can conclude that dry steam fields possess unambiguous cost advantages over other sources of energy for electricity generation, and that some wet steam fields have a probable cost advantage. The structure of costs in geothermal power production is similar to that of hydroelectric plants. Almost all costs are capital costs, of drilling, pipeline, and generating facility, with small charges for maintenance.

1.2 The Institutional Environment

In a later section the implications of institutional peculiarities for the behavior of the geothermal industry will be discussed. As background to that discussion, a brief summary of those features is presented here.

The sale of electricity is an activity regulated by statewide regulatory commissions in 47 states, including the State of California.[20] Entry into electricity distribution is virtually impossible for a new firm, since exclusive franchise areas covering practically the entire United States have already been granted. Commissions review electricity rates and determine an acceptable rate of return; hence the behavior of a regulated utility will differ from that of an unregulated competitive firm in terms of its demand functions for inputs and supply function of electricity.

Transmission of electricity is inseparable from production. Since construction of a new transmission line is a process which exhibits increasing returns because of right-of-way costs, an established utility located at a geothermal field may have a competitive advantage over newcomers. To some extent this advantage can be overcome if the Federal Power Commission requires the owner of an interstate transmission line to wheel power for other producers if it has excess capacity.

The production of energy from geothermal steam also brings producers under the purview of various agencies with regulatory jurisdiction over environmental effects. These reviews have imposed delays and costs on the development process which we will ignore except for this recognition of their existence.

At the other end of the production process is the acquisition of land. Geothermal energy is a commodity fixed in location, and access to steam depends on access to land. Private, state and Federal lands lie above the resource, and the owner of the land is in a position to receive rent for the use of his resource, either in the form of a continuous royalty payment or a lump sum. On private land, leases which have been examined by other researchers are pure royalty and rent leases.[21] On Federal lands all lease sales to date have involved both lump sum payments and royalties.

The Bureau of Land Management (BLM) administers the exploration and development of geothermal resources on Federal land. The BLM takes three major actions in regard to geothermal development: it classifies lands, it issues prospecting permits, and it leases lands for exploration and production. Lands may be classified as prospective geothermal resource areas (PGRA) or known geothermal resource areas (KGRA). A PGRA is so classified on the basis of surveys carried out by the United States Geological Survey (USGS) which indicate a possibility that a geothermal reservoir may be found there. A PGRA becomes a KGRA in two ways: 1) evidence based on survey drilling that a field is capable of producing a commercially usable fluid, or 2) requests for a noncompetitive lease in the same area (and in a specified time period) by two or more "knowledgeable" firms. When a tract must be offered for competitive bids, the competition takes the form of "bonus" bids--a cash payment for the lease, which will contain a provision for royalty payments of ten to fifteen percent of gross revenue from steam. Bids must be accompanied by fifty percent of the total bid, with the remainder payable when the lease is awarded. At that time various other bonds are required. Leases are for a term of ten years with renewal for from five to eighty years. The BLM has asserted the right to refuse all bids if it considers the high bid too low.

A "grandfather right" is conferred on anyone who held a mineral lease on and actively explored for geothermal steam on or near land offered for sale at competitive bids. The holder of a grandfather right will be awarded a lease if he meets the high bid. Leases are also transferable after being awarded.[22]

Two additional provisions of the leasing program are of interest. A lease can be terminated, or renewal refused, if the developer does not actively pursue exploration or development, although the Federal leasing program is too new to give instances of enforcement. To promote competition in the industry, no firm may hold Federal leases for more than 20,480 acres. If a firm puts land which it leases into a unitized* field, the acreage no longer counts against its quota.[23]

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*"Unitization" is the creation of a single management group which controls production from all wells topping a field.

Footnotes to Chapter 1

1. H. Christopher H. Armstead, "What is Geothermal Energy," in Geothermal Energy, Review of Research and Development, H. C. H. Armstead, ed., Unesco Press, Paris, France, 1974.

2. A. Kaufman, "The Economics of Geothermal Power in the United States," Geothermics (1970), Special Issue 2, U.N. Symposium on the Development and Utilization of Geothermal Resources, Pisa, 1970, Vol. 2, Part 1, 967-973, and R. James, "Power Station Strategy," in ibid., Vol. 2, Part 2, 1676-1687.

3. For a clear and readable discussion of geological and geophysical explanation of the nature of geothermal energy, see Sir Edward Ballard, "Basic Theories," and Giancarlo Facca, "The Structure and Behavior of Geothermal Fields," in H. C. H. Armstead, ed., Geothermal Energy.

4. J. H. Smith and G. R. McKenzie, "Wairakei Power Station, New Zealand-Economic Factors of Development and Operation," Geothermics, Vol. 2, Part 2.

5. R. James, "Power Station Strategy," Geothermics, Vol. 2, Part 2.

6. D. A. McMillan, Jr., "Economics of the Geysers Geothermal Field, California," Geothermics, Vol. 2, Part 2, 1705-1714.

7. Energy from Geothermal Resources, Report prepared for the Subcommittee on Energy of the Committee on Science and Astronautics, U.S. House of Representatives, 93rd Congres, May, 1974.

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13. J. H. Smith, "Collection and Transmission of Geothermal Fluids," in H. C. H. Armstead, Geothermal Energy.

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16. Energy from Geothermal Resources.

17. Kaufman, "Economics of Geothermal Power."

18. Energy from Geothermal Resources.

19. San Joaquin Nuclear Project, Draft Environmental Impact Report, p. 6.1-33.

20. L. Courville, "Regulation and Efficiency in the Electric Utility Industry," Bell Journal of Economics and Management Science, Spring 1974, Vol. 5, No. 1, 53-74.

21. Michael Sullivan, Steven McDougal, F. V. Huntley, "Patterns of Geothermal Lease Acquisition in the Imperial Valley, 1958-1974," University of California, Riverside, August, 1974.

22. Energy from Geothermal Resources.

23. "Geothermal Resources: Leasing on Public, Acquired, and Withdrawn Lands," Federal Register, Vol. 38, No. 245, Part II, Friday, December 21, 1973.

CHAPTER 2

THE VALUE OF A GEOTHERMAL LEASE

2.1 Economic Rent and Geothermal Energy

Economic rent can be defined as that part of the income of a factor of production above the minimum amount required to attract the factor into a particular use. The price of a factor is determined on the margin, by the amount required to attract the least willing factor into use. In competitive markets, a single price prevails for all identical goods. Suppose there are three individuals, each holding a single unit of some good. Person A is willing to sell his unit at $1, person B at $2, and person C at $3. Suppose further that at a price of $3 each, three units of this good will be purchased by some fourth person, so that A, B and C each sells his good for $3. Then A earns $2 rent, B earns $1 rent, and C just receives what is necessary to induce him to sell.

Our hypothesis is that geothermal energy generates economic rent, in that the investment and operating costs required to extract steam from the ground and to use it to generate electricity are less, per kilowatt-hour produced, than the price of electricity. Since geothermal resources are small compared to the amount necessary to generate _all_ electricity, market competition cannot remove the rent inhering in the resource. The cost advantage of geothermal energy will, if all relevant markets are competitive and all electricity is sold at the same price, accrue to the owner of the geothermal resource in payments for the right to extract the resource. If markets are not perfectly competitive, the distribution of the rent depends on features of the institutions and markets for mineral rights, steam, and electricity.

Portions of the economic rent attributable to the geothermal resource can be captured by any of four groups: electricity consumers, in the form of lower prices; electric utilities, in the form of higher total profits, possibly acquired through overcapitalization in response to rate of return regulation; by steam developers, depending on the relation between the price of steam, the cost of extracting it, and the cost of a lease; or by landowners, as royalties, rents, or lump-sum sales. Tax laws, the degree of competition, differences in knowledge about the nature and magnitude of the geothermal resource, demand and supply elasticities, and effects of regulation interact to determine the exact distribution of rent. It is necessary to work through all these effects to predict the likely rates of return received by geothermal steam developers. We will then test these predictions with estimates of lease payments.

Three markets must be considered simultaneously: the regulated market in which utilities sell electricity; the free but complex market in which one or a small number of utilities buy steam from a potentially larger number of suppliers; and the market in which suppliers purchase leases from landowners.

It is necessary to distinguish between the capitalized value of the economic rent of geothermal land and the price of a lease. Under certain special conditions the two are equal. If land is owned privately, if leases are freely transferable, if steam development and electricity generation are characterized by free entry and perfect competition, and if information is freely available and certain, leases will sell at the capitalized value of rents. In general, at competitive auctions they sell for less if uncertainty and/or a small number of bidders are present.

Strictly speaking, the price of a lease would under ideal conditions equal the capitalized value of economic rent plus the opportunity cost of land. The opportunity cost of land would be the highest value alternative use which must be foregone in order to exploit the goethermal resource. If a tract of land has no alternative use, or if geothermal development does not alter its usability for other purposes, opportunity cost will be zero. In either of these cases, under conditions of perfect competition among landowners, the supply of geothermal land will be perfectly inelastic--that is, a constant amount will be available independent of price. Naturally, geothermal lands will differ in their stage of development--from exploration to production--and in quality of steam and cost of winning it. Exploration for and development of geothermal resources is responsive to prices, so that perfectly inelastic supply of land does not imply perfectly inelastic supply of steam.

A substantial amount of geothermal land is owned by the Federal government, and leases on that land are sold at auction with sealed bids by the Bureau of Land Management. The Bureau has the authority, which it has exercised, of rejecting any high bid. However, the decision to reject a bid usually reflects an estimate of a "reasonable" bid, and cannot be interpreted as evidence that the Bureau itself has an elastic supply curve of geothermal land. We will assume that geothermal land is supplied inelastically by the Bureau, and that opportunity cost can be neglected. To the extent that this is incorrect, we will have overestimated the magnitude of economic rent. However, that error will only affect the share of rent accruing to the Federal government. This public share will be reduced, but all other shares will be unaffected.

2.2 Monopoly Power and Rent

As long as the market for leases is competitive, the price of a lease is determined by the value of steam output from the leased land, and steam price and quantity decisions are independent of lease prices. We can with these assumptions analyze just the steam market and the electricity market without considering what happens on the land market. The amount of economic rent that forms the basis for the lease price will depend only on the structure of the steam and electricity markets, and the lease price will equal the present value of such economic rent if all relevant markets are competitive.

To illustrate the dependence, assume that the market for steam has a single buyer and many competitive sellers of steam, and that the cost per unit of steam is constant for all amounts of steam extracted up to the capacity of the field. The buyer will maximize profits subject to the supply curve of steam. The industry steam supply curve is found by adding up the amount each firm will produce at any fixed price. With constant unit cost of extraction, the industry will supply any amount of steam from zero to the capacity of the field at a price equal to average cost including normal profits (exclusive of leasing cost or rent). Supply will be zero at any lower price and equal to capacity at any higher price. If the utility offers a price equal to average cost, it will get the entire output of the field (or as much as it wants); it will receive the maximum profits; each supplier will just earn normal profits; and rents or lease prices will be zero. As long as the utility's cost of producing electricity using alternative fuels is greater than the cost of production using geothermal steam priced at average cost, the utility will be willing to buy geothermal steam. The quantity it takes will be the quantity at which its increase in total production cost from producing one more kw using geothermal steam equals the increase in cost from producing one more kw using another energy source. If this "marginal" cost of electricity is less for geothermal generation than other means of producing electricity, even when the entire capacity of the field is exploited, the utility will purchase the maximum amount of steam.

The assumption of constant average cost is, of course, unrealistic. As the capacity limit of the field is reached, the new wells will come in at higher cost and will be less productive. Also the producers' field management might be altered by utility behavior. Thus, by offering a higher price the utility could gain more steam, although the life of the field might be shortened.

If the market for geothermal steam is the only market in which the utility is a monopsonist, we can derive mathematical expressions for the price and quantity of steam it will buy. Let $P_s(S)$ be the inverse supply curve of the steam industry. With increasing marginal cost, the construction of the geothermal steam industry supply curve is only simple if we assume that the activities of one producer do not affect the production conditions affecting another. That is, assume that if firm 1 increases its rate of extraction and that all else remains the same, then the rate of extraction obtained by firm 2 does not vary. Then the industry supply curve is simply the horizontal sum of each supplier's marginal cost curve.

Assume that the utility sells electricity at a fixed price P_e and purchases oil at a fixed price P_q, as would be the case on competitive markets, but that it is the sole buyer in the market for steam. Its production function using oil is $e = f_q(Q)$, with steam $e = f_s(S)$, where Q and S are quantities of fuel oil and steam, respectively. $P_s(S)$ is the price at which quantity S of steam is supplied. It will act to maximize

$$\pi = P_e[f_q(Q) + f_s(S)] - P_qQ - P_s(S)S.$$

First order conditions for a maximum are

$$\frac{\partial\pi}{\partial Q} = P_e f_q'(Q) - P_q = 0, \text{ and} \tag{1}$$

$$\frac{\partial\pi}{\partial S} = P_e f_s'(S) - P_s(S) - P_s'(S)S = 0. \tag{2}$$

Equation (1) states the familiar proposition that under competitive conditions demand for a factor of production is determined by equating the price of a factor to the value of its marginal product. Equation (2) differs from Equation (1) in that the utility can affect the price of steam by altering the quantity it buys, a phenomenon ruled out in the case of oil by the assumption of competitive markets. This phenomenon is captured by the term $P_s(S) + P_s'(S)S$ in Equation (2), which is analogous to the marginal revenue function of monopolistic seller. If the buyer of steam were one of many competitors, its purchase of steam would not affect the price of steam, so that $P_s'(S)$ would be zero. With a single buyer of steam, $P_s'(S)$ is equal to the slope of the supply curve, which is positive when increasing price calls forth an increased supply. Thus Equation (2) implies that the monopsonist utility pays a lower price and purchases less steam than a competitive customer would, assuming $f_s'' < 0$. Its profits will be the difference between cost and revenues at the price and quantity determined by solving the first order conditions together with the industry supply curve for an equilibrium price and quantity.[1] Under these conditions some, but not all, of the economic rent inhering in the geothermal resource will accrue to the electric utility. In contrast, with constant average cost the monopsonist buyer of steam can purchase any desired quantity by offering a price equal to the constant average cost of producing steam.

Realistically we cannot expect a utility to behave exactly as the theory of monopsony predicts. First, the theory requires that the utility have complete knowledge of the costs of steam production in order that it be able to predict the industry supply curve. Uncertainty about these facts may reduce the utility's ability to capture rents. Second, any countervailing monopoly power held by steam suppliers will enable them to claim some rents which would accrue to the utility under pure conditions of one buyer and very many sellers. Nevertheless, the qualitative conclusion remains that if there is only one buyer of steam some of the rent inhering in the geothermal resource will accrue to that buyer. If steam sellers also possess monopoly power, some rent will also accrue to them.

2.3 Regulation and Rent

We have assumed up to now that essentially the only element of monopoly is in buying steam. If the utility is also the sole supplier of electricity, we can make simple revisions in the first order conditions of profit maximation to include the effect of monopoly in selling electricity. If we replace the price of electricity, P_e, with marginal revenue, equal to $P_e(e) + P_e'(e) \cdot e$, we can demonstrate that the output of electricity is smaller, and the price higher, than under competitive conditions. However, in most cases the utility is a regulated monopolist, and prediction of its behavior must take account of the effects of regulation. The theory of the regulated firm is by no means fully developed, and, in any event, the nature of regulation varies sufficiently from company to company that it is doubtful that a single theoretical model is appropriate.

We confine our inquiry to the following question--is there any theory under which the utility would pay a price for steam that would cause the lease prices of geothermal land to equal total rent? No matter how the price of steam is determined, with a competitive steam industry the amount of steam generated is independent of the amount paid for leases. The price of steam will always be set at a level which just leaves steam developers with normal profits. The true rent of geothermal land is found by comparing the cost of production (excluding leasing costs) of electricity using geothermal steam with production cost using the cheapest marginal source of energy. If the PUC could make the utility act as if it were a perfect competitor, the landowners would receive all these rents in the form of lease payments. The utility would then earn only normal profits, as would the steam suppliers. All other differences between geothermal production cost and the cost of production in the marginal plant, which determines price to the consumer, would go to landowners. Only if regulators set prices equal to an appropriate fixed proportion of average cost <u>and</u> the demand for electricity is elastic will a profit-seeking, regulated firm behave as if it were competitive. Unfortunately, no PUC achieves this best of all possible worlds.

One widely held theory of the effect of regulation, proposed by H. Averch and L. L. Johnson (A-J),[2] holds that when regulators specify the rate of return on capital investment that a firm may earn (between the competitive rate and the rate earned under monopoly conditions), the firm will adopt a capital-labor ratio larger than that which minimizes the cost of producing its chosen level of output. The theory has no general implications as to whether the amount paid for a lease by a developer will exceed or fall short of the economic rent that would be generated if all markets were competitive. Indeed, if it could be shown that under rate of return regulation the price of steam, and hence the amount supplied would exceed the competitive supply, we would conclude that lease payments exceed the economic rent generated under competition.

The elasticity of supply of steam, the elasticity of demand for electricity, properties of the utility's production function, and the stringency of rate of return regulation all interact to determine the relation between lease payments and rent. Different influences, however, act in opposite directions so that it is conceivable that a regulated utility will pay more for steam than would a firm behaving in a perfectly competitive fashion. Monopoly output restriction and monopsony input restriction lead to a lower price and quantity of steam than in competitive conditions. The tendency to overcapitalize predicted by A-J and other regulatory theories would work in an opposite direction if geothermal energy production involved higher capital costs to the utility than any other process.

Without substantially more data, we have no unambiguous explanation of the relation between economic rent, rates of return, and lease payments. However, some rough estimates in Table 2.1 of relative capital and operating costs of new plants using other sources of energy shed some light on this relation. A power plant using geothermal energy has a <u>lower</u> capital cost per kw capacity than a power plant using oil, coal or nuclear energy. Moreover, if the utility purchases steam, the ratio of capital to operating cost is also lower for a geothermal power plant than for any other except oil. Hence the desire to over-capitalize would lead the utility to prefer nuclear plants, for example, to geothermal if

TABLE 2.1

OPERATING COST AND CAPITAL COST FOR
VARIOUS TYPES OF NEW POWER PLANT

Coal	Capital	$670/kw installed capacity (11.8 mills/kwh)*
	Fuel & Operating	11 mills/kwh**
Nuclear	Capital	$800-1000/kw installed capacity (14.1 mills/kwh)*
	Fuel & Operating	8.5 mills/kwh
Oil	Capital	$390/kw installed capacity (6.9 mills/kwh)*
	Fuel & Operating	11 mills/kwh***
Geothermal		
Purchased steam @ 2.5 mills/kwh	Capital	$105/kw installed capacity (2.1 mills/kwh)*
	Operating	2.8 mills/kwh
Integrated operation	Capital	$196/kw installed capacity (3.9 mills/kwh)*
	Operating	1.2 mills/kwh

*Based on a 12% discount rate, 80% load factor for oil, coal, nuclear; 90% load factor for geothermal.
**Based on coal in Utah at $16/T.
***Based on $7/bbl oil.

Source: Coal, Nuclear, and Oil: San Joaquin Nuclear Project, Draft Environmental Impact Report, pp. 1.1-32 and 6.1-33. Geothermal: Kaufman, "Economics of Geothermal Power."

their overall costs were equal. This means that the regulatory effect works in the same direction as the monopoly and monopsony effects, reducing the equilibrium price and quantity of steam and hence the value of a lease.

If the utility were able to run a fully integrated operation and include steam-winning investment in its rate base, the regulatory effect could result in an increase in the desirability to the utility of geothermal energy production. With integrated operation the ratio of capital to operating cost is larger for geothermal production than for any other process. Hence if the elasticity of demand for electricity is sufficiently high, the utility should be willing to pay more for a geothermal resource than is justified by the lower cost of producing electricity from geothermal energy. In this case the utility will either supplant the developer, by outbidding him for leases, or will purchase steam at a price below that which would prevail in the complete absence of regulatory effects. We conclude that if a market for steam exists, the price of steam and hence the value of a lease will be less than we would observe if all markets were perfectly competitive.

2.4 Vertical Integration and the Price of Steam

In the last section we argued that some of the markets we have discussed may disappear, due to vertical integration, and that the possibility of integration places additional constraints on the allocation of rent. In this section we examine vertical integration, and its implications, in detail.

The essentially static approach developed thus far neglects certain peculiar features of the steam transaction, which have to do with time, uncertainty, and investment planning. Arrow has argued that in a multistage production process uncertainty in the delivery of an intermediate product leads to vertical integration, so that the "downstream" user can control deliveries of his inputs.[3] Although rates of output from operating wells have been extremely reliable, production from new wells cannot be guaranteed in advance. A 100 MW power station is about minimum efficient scale, and at the Geysers costs on the order of $11 million[4]--hence the costs of unreliable steam supply are substantial. On the supply side the output of new wells cannot be sold unless a power station of adequate size exists.

If a well is already drilled, the developer could be forced to accept any price of steam above the minimal operating costs, which are the only components of variable cost. Such a developer would accept a price which did not pay more than a small return on his invested capital, since his only alternative is to have no return at all. Hence the developer will want to negotiate a price in advance of drilling. Similarly, a utility with an unused power plant would be willing to buy steam at a price which reduced his return on capital to almost zero, although he could achieve higher returns if he could make contracts in advance of construction. Hence a steam developer with excess steam or utility with a new power station is in an extremely unfavorable strategic position. Normally we model exchanges as a sequence of spot transactions with prices and quantities free to vary with market conditions. For the geothermal steam transaction, both sides will prefer to make future contracts to avoid exploitation of their locked-in position. Unfortunately, no active future market in steam deliveries exists because of their fixed geographical location.

Forward integration by the steam supplier is precluded by the difficulty of entering the electric utility industry. The possibility of backward integration by the utility certainly exists, and A-J models would predict that it would be advantageous because of the very high ratio of capital to operating cost in integrated operation. This has not happened, although this possibility may be as important as monopsony power in keeping down the cost of steam. The substitute for integration adopted at the Geysers is one of a long-term contract for steam delivery at a specified price per kwh of electricity generated by the purchaser, with an escalator clause tied to the price of alternative fuels.

The contract between Union and PG&E provided in 1971 for a steam price of 2.5 mills per kilowatt hour of electricity generated by PG&E. In 1973 the escalator clause raised the price of steam to 3.15 mills/kwh; in 1974 the price increased further to 3.73 mills/kwh. The price as of March 21, 1975 was 7 mills/kwh.[5]

2.5 Internal Rates of Return and Lease Payments

Although data on marginal costs are unavailable, we can use published reports of average costs of geothermal energy and estimates of the costs of alternative energy sources to make a rough estimate of the economic rent associated with the geothermal resource at the Geysers. If we assume that when steam is purchased the regulatory bias is small, but that the same bias encourages utilities to integrate backward into steam production, the present value of economic rent places an upper bound on the value of a lease. Alternatively, we can estimate the value of a lease from current market conditions (where integration backwards has not occurred), using the market price of steam to estimate economic rent. In the next section we will also investigate the dependence of the developers' rate of return on lease cost and the price of steam.

Given tax laws, costs, and revenues, there is a fixed relation between the value of a lease and the rate of return. That is, the value of a lease is the present value of economic rents, using the rate of return as a discount rate. We may view either as the independent variable--that is, we can compute the value of a lease if a firm uses an internal discount rate, r, or we can compute the internal rate of return when the price of a lease is p. The following graphs and tables present these calculations with the cost and revenue estimates stated in Table 2.2.

TABLE 2.2

COSTS AND REVENUES OF 100 MW POWER PLANT
ASSUMING 5 MW PER WELL

20 wells @ $350,000 per well[6] =	$7,000,000
Pipelines @ $10 per kw[7] =	1,000,000
TOTAL Steam Investment	$8,000,000
Power plant investment[8] =	$11,600,000
Well operating costs per year[9] =	$600,000
Plant operating costs per year @ $.00045/kwh[10] =	$355,000
Steam revenue per year @ 2.5 mills/kwh output and 12.5% royalty =	$1,725,000

The Federal leases at the Geysers contain a provision for royalties at 12.5 percent of gross revenue from selling steam, which we take off the top. We assume a 90 percent load factor on the 100 MW plant. 100 MW capacity was chosen because data are readily available for that size, and because economies of scale are small for larger plants. Sources for other figures are referenced in Table 2.2. We obtain lease cost by assuming a 40 acre per well spacing and 5 MW per well capacity.[11] The figures are intended only as rough estimates. They support inferences about the relative importance of various factors and the effect of different tax treatment, but estimates of rates of return are only as accurate as the estimates of cost and revenues. If anything, production cost estimates are high and revenues low.

Rates of Return to Geothermal Investment--No Backward Integration. We use the data presented in Table 2.2 to estimate costs and revenues from geothermal energy production, taking the present market structure (no backward integration by utilities) as given. From these costs and revenues we compute rates of return, over 20-year life of a well, on investment (including varying lease costs) in steam production, excluding investment in power production from steam. We compute rates of return to steam production (as a function of lease cost) at a steam price of 2.5 mills per kilowatt-hour of electricity produced under five assumptions about tax structure.

(1) No tax.

(2) A corporate profits tax of 48 percent with deductions allowed for operating cost and straight-line depreciation of investment over 20 years.

(3) The tax treatment accorded to the Geysers in Reich, et al., viz 22 percent depletion allowance and expensing of intangible drilling costs.

(4) The depletion allowance alone.

(5) Expensing of intangible drilling cost, currently allowed by the law, abolishing percentage depletion for large firms.

In Table 2.3 the rates of return earned with various prices per acre of land are tabulated. The relation between rate of return and price of land is graphed in Figure 2.1.

Rates of Return to Investment in Fully Integrated Geothermal Power Production. We next assume complete vertical integration to the sale of electricity and find rates of return versus lease cost with the revenue based at 6 mill/kwh and 7 mill/kwh price of electricity. In this integrated approach it is impossible to treat depletion or royalties without raising accounting problems of defining an internal price of steam, so that we simply compute before-tax rates of return and after-tax rates of return under a flat 48 percent CPT, presented in Table 2.4 and Figure 2.2.* Although power plants last longer than 20 years, at these rates of return the difference between 20 and 30 year life would increase rates of return by less than 10 percent.

The after-tax rate of return vs. lease cost tables for the two cases (no integration and complete integration) give a prediction of the value of a lease under perfect competition in all markets, and can be compared (when appropriately adjusted for uncertainty) to actual payments to test the hypotheses of perfect competition.

It will be noted that the after-tax rate of return (Table 2.3) is highest with expensing and the depletion allowance, but the depletion allowance is being phased out under current tax laws. There will be general equilibrium consequences of the removal of the oil depletion

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*A 12.5 percent royalty and a 22 percent depletion allowance would roughly cancel out, whatever the price of steam, because the tax saving from the depletion allowance is just under 11 percent of the selling price.

TABLE 2.3

RATE OF RETURN VS. LEASE COST
(NO BACKWARD INTEGRATION)
2.5 MILL STEAM

Before tax rates of return selling steam with well spacing of 1 per 40 acres and various per acre costs, assuming 20 year life:

Price per acre ($)	Rate of return (%)
-0-	12.8
1,000	11.3
3,000	8.8
5,000	6.9

After-tax rate of return with corporate profits tax (CPT) of 48% and no expensing or depletion allowance:

Price per acre ($)	Rate of return (%)
-0-	7.4
1,000	6.5
3,000	5.0
5,000	3.9

After-tax rate of return with expensing and depletion allowance:

Price per acre ($)	Rate of return (%)
-0-	16.8
1,000	13.9
3,000	9.8
5,000	7.0
7,000	4.9
9,000	3.2
10,000	2.5

After-tax rate of return with percentage depletion:

Price per acre ($)	Rate of return (%)
-0-	10.7
1,000	9.3
2,000	8.1
3,000	7.1
4,000	6.1
5,000	5.3
6,000	4.5
7,000	3.8

After-tax rate of return with expensing of intangible drilling cost:

Price per acre ($)	Rate of return (%)
-0-	11.7
1,000	9.8
2,000	8.3
3,000	7.0
4,000	6.0
5,000	5.2
6,000	4.5
7,000	3.9

FIGURE 2.1 LEASE COST VS. RATE OF RETURN FOR VARIOUS FACTORS

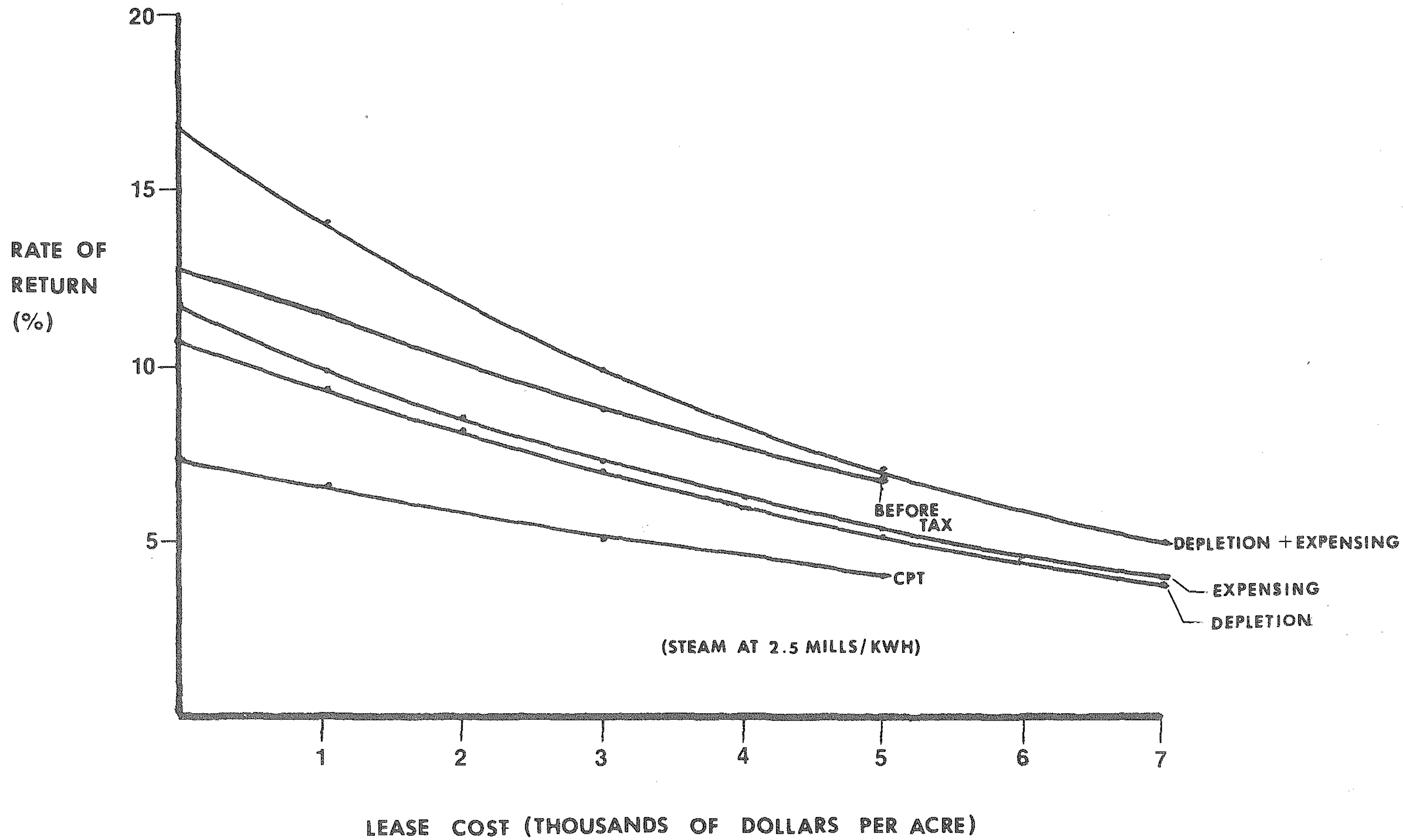


TABLE 2.4

LEASE COST VS. RATE OF RETURN
INTEGRATED OPERATION

Before-tax rates of return:

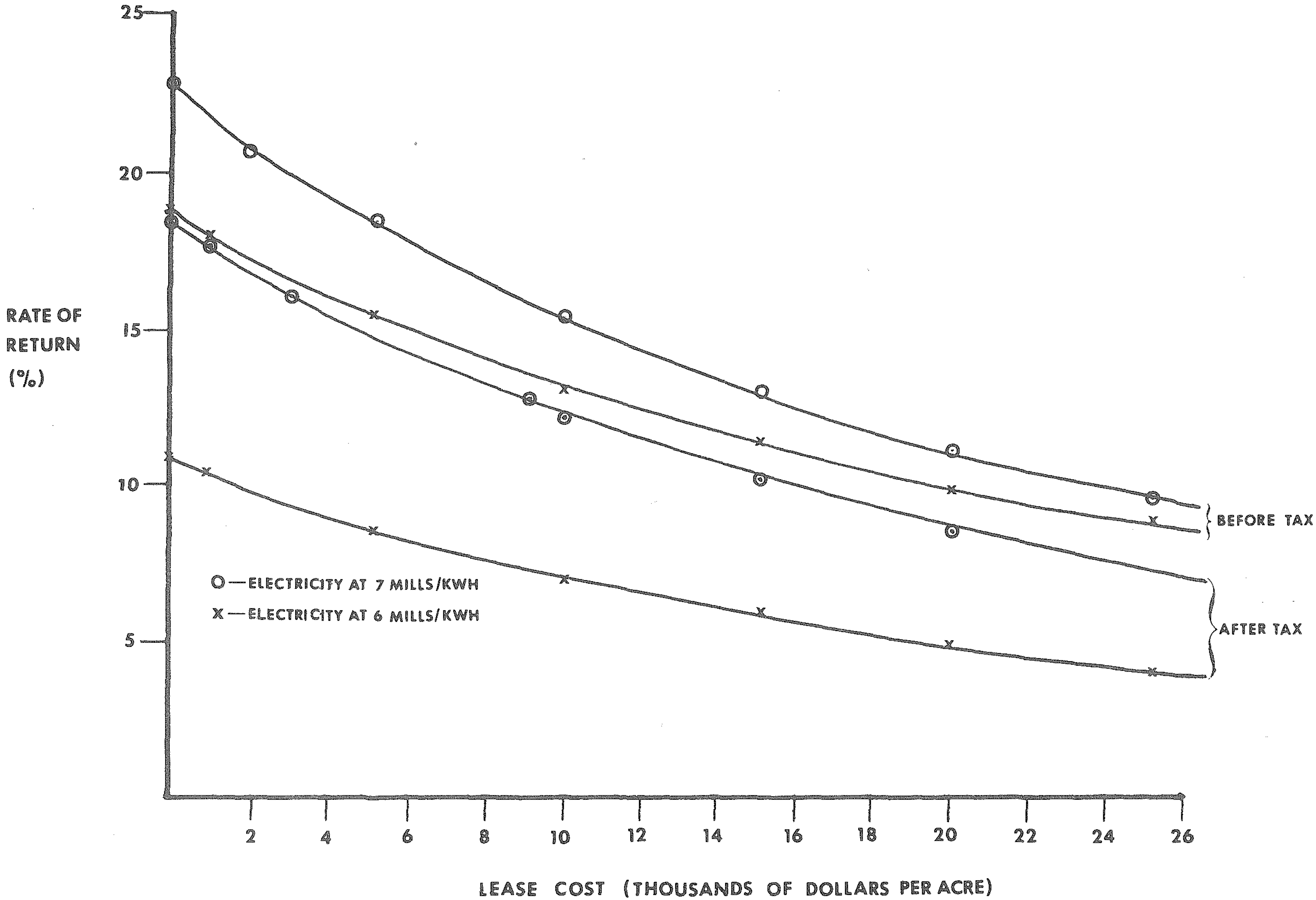
Lease cost ($)	Rate of return (%)
	6 mills*
-0-	18.6
1,000	17.8
3,000	16.3
9,000	12.8
10,000	12.3
15,000	10.3
20,000	8.6
	7 mills*
-0-	22.9
2,000	21.1
5,000	18.7
10,000	15.6
15,000	13.2
20,000	11.3
25,000	9.7

After-tax rates of return:

	6 mills*	7 mills*
-0-	10.8	18.8
1,000	10.3	18.0
5,000	8.7	15.6
10,000	7.1	13.3
15,000	5.9	11.5
20,000	4.8	10.0
25,000	4.0	8.8
30,000		7.8
40,000		6.2
50,000		4.9

*Price of electricity per kilowatt hour.

FIGURE 2.2 LEASE COST VS. RATE OF RETURN FOR AN INTEGRATED OPERATION



allowance not considered herein. To the extent that it has served to attract capital to oil production, the depletion allowance has served to maintain low oil prices and higher levels of supply. Removal of the depletion allowance can be expected to result in higher prices of oil, which will in turn raise the rents accruing to alternative energy sources, and hence other things being equal, the price of geothermal steam. This will tend to counteract the fall in rate of return due to elimination of the depletion allowance at constant lease prices predicted by the above table.

To include the effects of the depletion allowance and royalties in our estimate of lease cost, we assume that the market is not integrated, and that the utility pays a price for steam which leaves it just a 10 percent rate of return. We find the rates of return accruing to steam developers under these conditions at two prices of electricity. Taking 6 mills as the price received per kwh of electricity, total revenue is \$4,720,000 annually, and net revenue is \$4,366,000 per year; for 20 years \$11,600,000 must earn \$1,360,000 per year to have a 10 percent internal rate of return. Hence steam cost can be approximately \$3,014,600 per year. If 7,884 hours times 100,000 = 788,400,000 kwh are generated, a steam price of 3.82 mills/kwh will produce that cost. This is about the 1974 price of steam, and hence is the figure most likely to represent expectations when leases were sold in 1974. We can now rework the value of a lease with the figures in Table 2.5, which are graphed in Figure 2.3. Thus, reading off the graph, a rate of return to geothermal steam developers of 10 percent (after taxes) with steam prices of 4 mills leads to a lease price of \$10,000. At an electricity price of 12 mills/kwh rates of return will be almost double those at 6 mills when depletion and expensing are allowed. With the straight 50 percent CPT, or with no tax, a price of 12 mills/kwh will double rates of return until lease costs become very large--\$20,000 per acre or more--at which point the rate of return will be less than

TABLE 2.5

LEASE COST VS. RATE OF RETURN

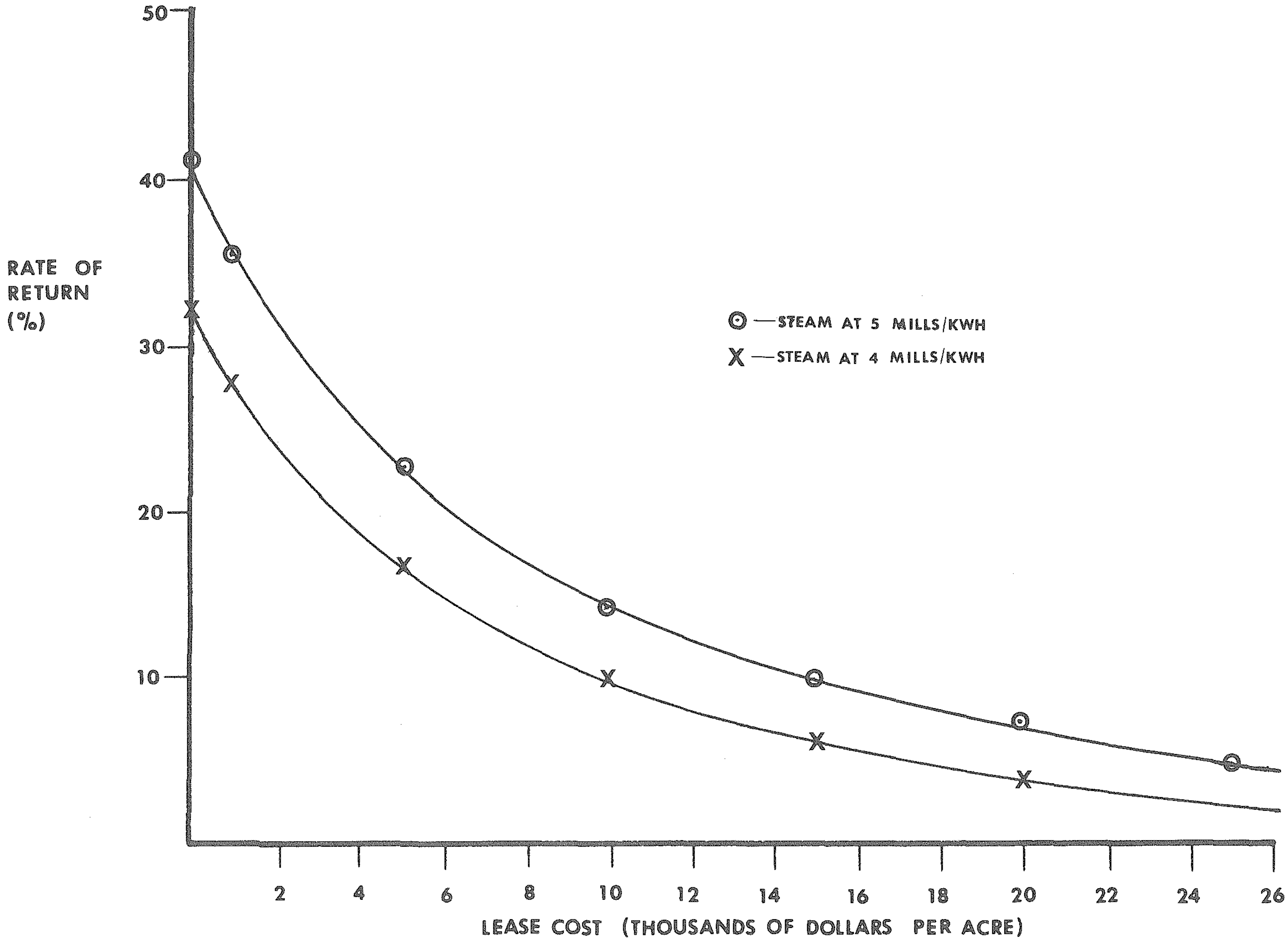
Price of electricity 6 mills/kwh, steam price approximately 4 mills.

Lease cost ($)	After tax Rate of return (%)
-0-	32
1,000	27
5,000	16.3
10,000	10
15,000	6.3
20,000	3.7

When the price of electricity is 7 mills/kwh, the price of steam can be 5 mills. The results are presented below.

-0-	41.4
1,000	35.6
5,000	22.0
10,000	14.3
15,000	9.9
20,000	7.0
25,000	4.8

FIGURE 2.3 LEASE COST VS. AFTER TAX RATE OF RETURN WITH DEPLETION AND EXPENSING



double. These rates of return are all so high that precise calculation seems unnecessary.

One further dimension we may consider is the length of time between lease acquisition and the commencing of drilling and production. If we fix both the firm's discount rate and the price of a lease, we obtain the maximum delay immediately. Consider the case of 2.5 mill steam, depletion and expensing. With the 20 percent after-tax rate of return earned by oil companies in 1973 and a $500/acre lease, winning bidders can hardly afford any delay in getting into production, since they can earn only 17 percent if production begins immediately.

Unanticipated delays already have been encountered in the expansion of the Geysers field. Hence the value of a lease predicted in the preceding tables should be corrected to reflect the fact that revenues will not begin to accrue immediately after the purchase of a lease. We can do this by discounting the present value of ownership of an acre of land back from the date at which production commences to the time of acquisition.

For example, with a more normal 10 percent after-tax real rate of return and assuming no backwards integration (see Table 2.3), a lease is worth approximately $3,000 per acre (if expensing and depletion are allowed). At an $800 winning bid, a firm can wait about 13 years before this $800 accumulates to $3,000 of foregone principal and income. If the price of steam were high enough to capture all rents (the backwards integration-case--see Figure 2.3), a 10 percent rate of return makes an acre worth about $12,000. It takes 27 years for $800 to increase 15 times to $12,000.

If the Geysers field increased at a rate of 100 MW per year in generating capacity, the entire 2,500 MW field would be in operation in 25 years. Ten years might be a reasonable delay to expect in getting into operation, comparable to the time justified by the 2.5 mill price and a 10 percent rate of return.

Footnotes to Chapter 2

1. For an extended discussion of demand and supply under monopoly, see E. Mansfield, Microeconomics, New York: Norton, 1970, ch. 4.

2. Harvey Averch and Leland L. Johnson, "Behavior of the Firm under Regulatory Constraint," American Economic Review, Vol. 42, No. 5, December, 1962, 1053-1069.

3. K. J. Arrow, "Vertical Integration and Communication," Bell Journal of Economics, Vol. 6, No. 1, Spring, 1975, 173-183.

4. McMillan, "Economics of the Geysers."

5. Congressional Research Service, "Geothermal Energy," Issue Brief No. IB 74056, June 16, 1975.

6. Energy from Geothermal Resources.

7. McMillan; op cit.

8. McMillan; op cit.

9. Kaufmann; op cit.

10. McMillan; op cit.

11. Ibid.

CHAPTER 3

THE FEDERAL LEASING PROGRAM

3.1 Models of Competitive Bidding

Our source of data for testing hypotheses about the organization of markets relevant to the development of geothermal energy is the Federal geothermal leasing program.

We must once again revise the simple economics of geothermal energy to account for distinctive features of the Federal leasing program. It remains true that lease payments are price-determined, and that the price of steam is independent of the size of leasing costs. However, even if there is no collusion among bidders and perfect competition on all other markets, the winning bid for a lease need not equal the economic rent inhering in that tract of land. We will begin with a brief summary of some relevant propositions in the theory of competitive bidding, and then proceed to a statistical analysis of bids on Federal geothermal leases. In Chapter 4 we will compare results of this analysis with estimates of the value of a lease and predictions of how competitive firms will behave.

The theory of competitive bidding does not provide a complete, general theory of how individuals will behave in bidding situations of the type created by the Federal leasing program. It does, however, contain insights from which we can construct an analytical framework which suggests certain regularities we may observe in real bids. Three subjects are of interest: 1) the relation between the expected value of a tract and the size of bids; 2) the relation between the number of bidders and the size of bids; and 3) the effect of uncertainty about the value of a tract on the size and distribution of bids.

Models of bidding are based on either game theory or statistical decision theory. In all models a key concept is the expected value of the object offered, in this case a lease to use the geothermal resource underlying a tract of land. In Chapter 2 we argued that in a world of complete certainty the maximum price a developer would be willing to pay for a geothermal lease is the present value of net revenues attributable to ownership of the lease. In simple game-theoretic models of competitive bidding, the optimal strategy for each participant is to bid the maximum. These models are of an unrepeated sale of one object to the highest bidder at his bid, with a known or unknown number of participants, and assume either that each participant is certain of the value of the object or that each knows exactly how every other participant's valuation depends on his own.[1]

Many uncertainties arise in connection with geothermal development. The more important have to do with the physical and chemical description of the resource itself, the quality of the reservoir underlying the specific tract offered for lease, the time trend of input and output prices and changes in tax laws, environmental regulations, and utility regulations. We introduce these uncertainties by assuming that each developer has a probability distribution over costs of production revenues which will be generated by the tract offered. The <u>expected value</u> of a lease is the mathematical expectation taken over this probability distribution of the present value of net revenue.

In game-theoretic and decision-theoretic models of competitive bidding with uncertainty[2] about the value of a tract, it is demonstrated that if each player is risk-neutral, he will bid strictly less than the expected value of a lease.[3] There are no general results on how much less the bid will be. In decision-theoretic models of bidding the reasons for this result can be described heuristically. Each participant forms a subjective probability distribution over his opponents' bids, conditional on his estimate of the value of the lease. Possibly he does this by observing how they have behaved in the past. He also computes his expected profit conditional on winning the auction. This profit is a maximum, equal to the expected value of the lease, if he bids zero. It is zero if he bids the expected value, and negative if he bids more. Expected profit as a function of his bid is expected profit if he wins times the probability that all his opponents will bid less. This unconditional expected profit is zero if he bids zero--surely someone will bid higher than that--and zero if he bids his expected value. Continuity of the probability function of opponents' bids implies that unconditional expected profit is maximized if the bid is strictly less than the expected value of the object auctioned.[4]

If the bidder is risk-neutral, that is, if he is indifferent between \$X for certain and a lottery which pays Y with probablity P and Y', with probability (1-P), and for which $X = PY + (1-P)Y'$, then he will choose to maximize unconditional expected profit. If the bidder is not risk-neutral, the analysis is more complex, since two types of risk are present--the risk of the object having less value than the winning bid, and the risk of losing a prize worth more than the bid.[5] Since the issue of whether or not corporations are risk-averse and why is still the subject of much dispute, we will adopt the simple hypothesis of risk-neutrality on the principle of equi-probability of the unknown. With this assumption we conclude that bids are strictly less than the value of a lease.

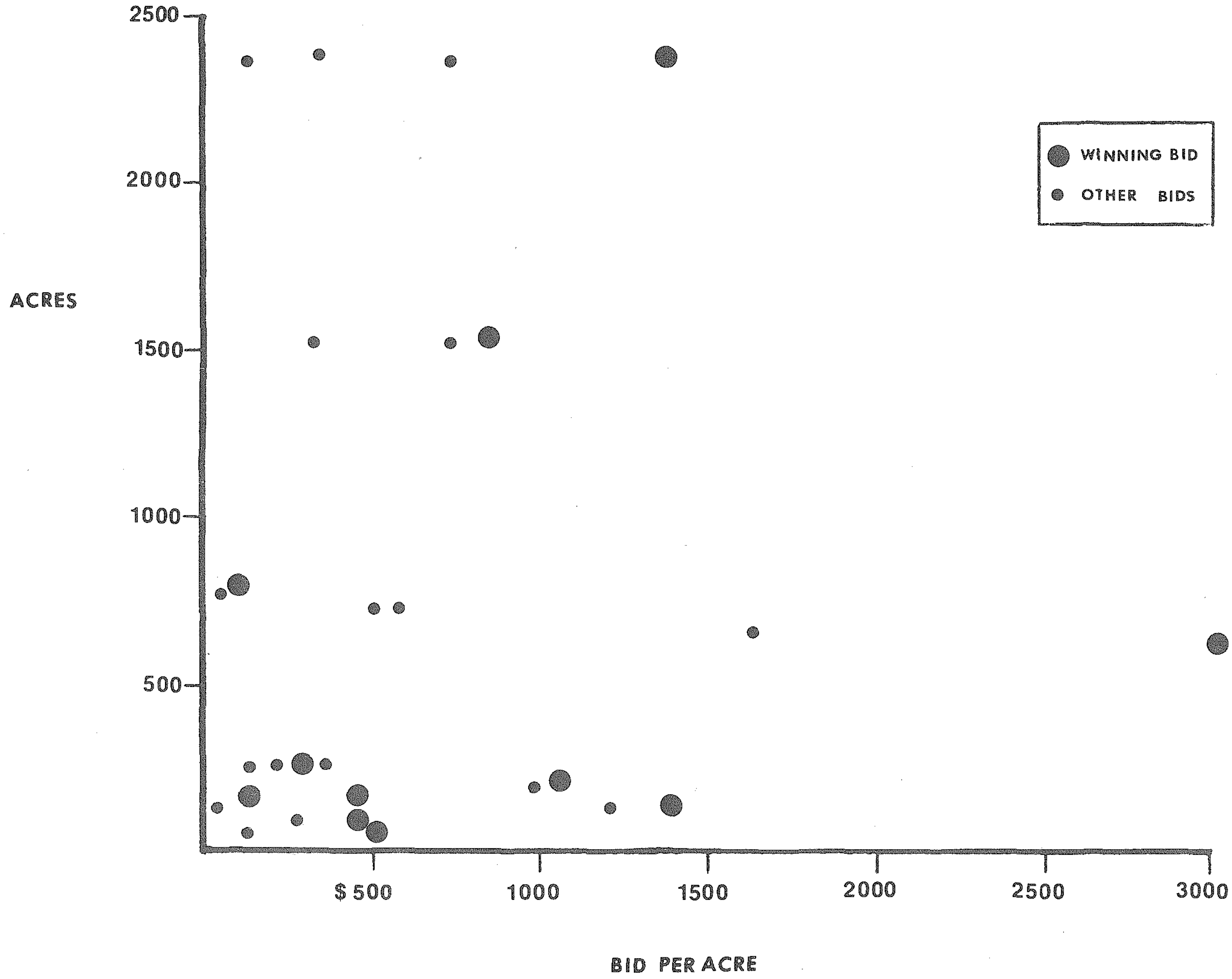
The decision-theoretic approach to competitive bidding has been applied many times to bidding for oil leases,[6] and hence may, despite its defects as a general theory, be useful as a description of how these firms will bid for geothermal leases.

A decision-theoretic approach leads to the further conclusion that as the number of competitors predicted in an auction rises, the optimal bid comes closer to the expected value. This result is useful in evaluating how rent is distributed among different parts of the geothermal market. The case of perfect competition in the market for land would be one in which there exist a large number of competitors. Even without explicit collusion, limitation of the number of bidders itself tends to produce an outcome more favorable to the bidders and potentially less favorable to the seller. Although the mechanism is different, the result is the familiar theorem about the Cournot solution in oligopoly. By collusion each bidder could be better off, but as long as each bidder consciously considers the interaction between his and other bids, the market works less well than under perfect competition. The lack even of a general theory of oligopoly leads us to be pessimistic about the existence of more general results about non-collusive bidding. We can, however, expect that with "competitive" bidding and small numbers of bidders the price of a lease will be less than predicted with perfectly competitive markets.

The decision-theoretic approach has been criticized on the grounds that it is in principle impossible to predict the behavior of competitors on the basis of subjective probabilities, because of the infinite regress of expectations and strategies in interpersonal decision problems.[7] By formulating the bidding process as a game and considering equilibrium strategies, we cut through this regress. Game theoretic models support the conclusion that with uncertainty bids will be strictly less than the expected value of a lease, but are ambiguous in their support of the contention that individual bids increase with the number of competitors.

Rothkopf[8] shows in a game-theoretic model that with an optimal strategy the bid submitted by a firm eventually decreases as the number of bidders increases, although the value of the winning bid increases. We can test Rothkopf's model against the decision-theoretic model (using data from actual bids submitted for Federal geothermal leases near the Geysers) in two ways. First, note that Figure 3.3 reveals some tendency for bids by an individual firm to be a maximum when the number of bidders is three, as Rothkopf's model predicts. However, we will later

FIGURE 3.1 BID PER ACRE VS. LOT SIZE AT THE GEYSERS



report on a regression analysis of bids versus number of competitors which tends to support the decision-theoretic model.

Game-theoretic models do shed light on another subject, the distribution of bids in a single auction. A particularly simple model appropriate to geothermal leasing was developed by R. Wilson.[9] The equilibrium strategy is to bid a certain fractile below the mean of one's posterior distribution function over the value of the prize. The model requires specific distributional assumptions--that each participant has a diffuse normal prior and samples from a normal population. In this case the population distribution goes through into the bid distribution. Bids will be normally distributed if each bidder follows an equilibrium strategy.

In multiple auctions the existence of constraints on the amount bidders can pay for all their winning bids, or interdependency between the number of objects won and the value of the object, complicates matters considerably.[10] Resale of leases raises additional considerations. Detailed original research into modelling the geothermal, or the similar, bidding process for oil leases on the Outer Continental Shelf (OCS) is required before such questions as the optimal distribution of bids for different tracts offered for sale simultaneously can be answered.

3.2 Statistical Analysis of Bids

The literature on competitive bidding suggested some general regularities in the distribution of bids offered on each tract. A specific empirical proposition about bids on Federal Outer Continental Shelf (OCS) oil leases is that on each tract bids are approximately log-normally distributed.[11] Hence we begin by performing a test to find if the logarithms of bids in geothermal lease sales are normally distributed. We consider the bids on each tract, for example the seven bids on Tract 1 at the Geysers (Table 3.1), to form a single distribution, and test the hypothesis that the distribution was log-normal.

TABLE 3.1

GEOTHERMAL LEASE SALES

Date: January 22, 1974

Location: Sacramento, California

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
Geysers	2,340	1	Shell Oil Company	3,200,000.00	CA 949
			Signal Oil & Gas Co., et al.	1,516,660.00	
			Union Oil Co. of Calif.	774,867.60	
			Thermogenics, Inc.	264,420.00	
			Geothermal Resources Int'l., Inc.	50,333.40	
			Chevron Oil Co.	35,755.20	
			Northern California Power Agency	23,400.00	
	1,534	2	Shell Oil Company	1,300,000.00	CA 950
			Union Oil Co. of Calif.	1,163,953.18	
			Natomas Co.	451,000.00	
			Thermogenics, Inc.	193,284.00	
			Dow Chemical Co.	38,516.87	
			Northern California Power Agency	15,340.00	
	175	3	Thermogenics, Inc.	22,050.00	CA 951
			Cecil Folmar	11,450.00	
			California Geothermal, Inc.	4,749.50	
			Union Oil Co. of Calif.	4,707.50	
	101	4	Union Oil Co. of Calif.	48,314.36	CA 952
			Signal Oil & Gas Co.	28,381.00	
			California Geothermal, Inc.	2,740.13	
	169	5	Union Oil Co. of Calif.	80,842.84	CA 953
			Ronald B. Shoen	10,369.84	
			Edward B. Towne	211.79	
	2,396	6	Union Oil Co. of Calif.	12,243.56	CA 954
			Edward B. Towne	2,346.35	
			Edward B. Towne	150.08	
	626	7	Union Oil Co. of Calif.	318,120.68	CA 955
			Signal Oil Co. (Gr.)	180,288.00	
	250	8	Signal Oil Co. (Gr.)	75,600.00	CA 956
			Union Oil Co. of Calif.	57,045.00	

Table 3.1 continued

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
Geysers	160	9	Occidental Petroleum Corp. (Gr.)	163,360.00	CA 957
			Union Oil Co. of Calif.	129,161.00	
			Signal Oil & Gas Co.	32,480.00	
	222	10	Occidental Petroleum Corp. (Gr.)	226,662.00	CA 958
			Signal Oil & Gas Co.	78,588.00	
			Union Oil Co. of Calif.	67,634.52	
			Thermogenics, Inc.	27,972.00	
	45	11	Union Oil Co. of Calif. (Gr.)	22,868.10	CA 959
			Signal Oil & Gas Co.	4,770.00	
	737	12	Signal Oil & Gas Co.	56,666.00	CA 960
			Union Oil Co. of Calif. (Gr.)	18,631.36	
			Michael Belzer	697.00	

Note: (Gr.) = Grandfather rights.
Tracts 7 and 9 were rejected as too low.

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
Mono - Long Valley	1,815	1	Chevron Oil Co.	18,459.36	CA 961
			Geothermal Resources Int.	9,080.00	
	1,895	2	Getty Oil Co., et al.	98,592.00	CA 962
			Chevron Oil Co.	25,073.63	
			Geothermal Resources Int.	9,480.00	
	1,773	3	Republic Geothermal, Inc.	515,767.07	CA 963
			Union Oil Co. of Calif.	281,504.76	
			Getty Oil Co., et al.	92,196.00	
			California Geothermal	52,507.37	
			Chevron Oil Co.	27,069.13	
	1,883	4	No Bids		
	2,309	5	No Bids		
	1,763	6	No Bids		
	2,277	7	No Bids		

Table 3.1 continued

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
East Mesa	2,240	1	No Bids		
	2,559	2	No Bids		
	1,868	3	Magma Power Company	4,203.00	CA 964
	1,920	4	No Bids		
	2,240	5	No Bids		
	2,240	6	No Bids		
	2,400	7	No Bids		
	1,437	8	Magma Power Co.	3,235.00	CA 965
	2,549	9	Republic Geothermal Inc.	432,810.01	CA 966
	2,560	10	No Bids		
	1,596	11	Republic Geothermal, Inc.	208,925.31	CA 967
	1,760	12	Magma Power Co.	3,960.00	CA 968
	2,240	13	No Bids		
	2,560	14	No Bids		
			LEASE SALE - May 29, 1974, Sacramento, Calif.		
Geysers	626	7	Natomas	2,055,000.00	CA 955
			Santa Clara (city)	2,000,000.00	
			Burmah Oil & Gas Co. (Signal)	1,087,000.00	
			Union Oil Co.	345,000.00	
			Occidental Oil Co.	335,000.00	
	160	9	Union Oil Co.	220,342.00	CA 957
			Occidental Oil Co.	220,000.00	
			Burmah Oil & Gas Co. (Signal)	192,650.00	

Table 3.1 continued

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
			LEASE SALE - May 10, 1974, Vale, Oregon		
Vale	1,347	1	Republic Geothermal	13,831.00	OR 1264
			Union Oil Co.	7,544.15	
			Magma Energy	7,476.79	
			LVO Corp. of Tulsa	4,108.86	
			LEASE SALE - July 30, 1974, Roosevelt Hot Springs, Utah		
Roosevelt Hot Springs	2,560	1	Union Oil	51,993.60	U-27383
			Gulf	23,372.80	
			Phillips	13,081.60	
	1,640	2	Phillips	87,543.20	U-27384
			Union Oil	62,090.40	
			Gulf	14,973.20	
	1,920	3	Phillips	9,811.20	U-27385
	2,453.5	4	Phillips	314,199.05	U-27386
			Union Oil	93,234.14	
			Gulf	22,400.73	
	1,644	5	Phillips	8,401.10	U-27387
			Al Aquitane	5,877.00	
	1,940	6	Phillips	248,391.58	U-27388
			Getty Oil	53,350.00	
			Union Oil	46,672.30	
			Gulf	17,709.00	
			Al Aquitane	6,139.19	
	1,961	7	Phillips	41,856.28	U-27389
	2,272.5	8	Phillips	62,902.80	U-27390
			Getty	28,412.50	
			Gulf	20,747.93	
	1,920	9	Getty	24,000.60	U-27391
			Gulf	17,529.60	
			Phillips	9,811.20	
			American Oil Shale Corp.	4,992.00	

Table 3.1 continued

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
Roosevelt Hot Springs	2,560	10	Phillips	13,081.60	U-27392
	2,480	11	Phillips	12,672.80	U-27393
	40	12	(Grandfather tract)		
			Phillips	2,335.20	U-12990
			A. L. MacDonald & Wn. L. (Gr.)	120.00	
			LEASE SALE - September 11, 1974, Brady's Hot Springs, Nevada		
Brady	988.85	1	Geothermal Resources, Inc.	6,500.00	
	640	2	Geothermal Resources, Inc.	6,500.00	
			Magma	1,497.00	
	640	3	No Bids		
	2,561.2	4	Magma	5,993.21	
	2,560	5	No Bids		
	2,512.56	6	No Bids		
	2,401.52	7	Hydro-Search, Inc.	15,108.61	
	143.37	8	Geothermal Resources, Inc.	1,000.00	

Tract 4 was rejected as too low.

KGRA	Acreage	Tract	Name of Bidder	Amount	Lease
			LEASE SALE - December 18, 1974, Reno, Nevada		
Beowawe	1,942.64	1	Chevron Oil Co.	15,074.89	
			Southern Union Production Co.	2,002.00	
	2,478.72	4	Chevron Oil Co.	505,088.77	
			Natomas	37,180.80	
	2,520.62	5	Getty Oil Co.	45,371.16	
			Burmah Oil & Gas Co.	35,742.39	
			Chevron Oil Co.	25,256.61	

Table 3.1 continued

KGRA	Acreage	Tract	Name of Bidder	Amount
Beowawe	2,467.83	6	Chevron Oil Co.	95,490.92
			Burmah Oil & Gas Co.	63,250.48
			Natomas	37,017.45
	2,418.53	8	Getty Oil Co.	30,231.63
Hot Springs	2,141.06	2	Chevron Oil Co.	115,274.67
			Getty Oil Co.	12,846.36
	2,560	3	Chevron Oil Co.	125,619.20
			Getty Oil Co.	23,040.00
Brady-Hazen	2,561.2	2	Natomas	51,224.00
			Union Oil Co.	27,148.72
	2,512.56	4	Natomas	37,688.40
	~2,500	5	Getty Oil Co.	45,371.16
			Burmah Oil & Gas Co.	35,742.39
			Chevron Oil Co.	25,256.61
	~2,500	6	Chevron Oil Co.	95,490.92
			Burmah Oil & Gas Co.	63,250.48
			Natomas	37,017.45
	~2,500	7	Getty Oil Co.	30,231.63

Source: U.S. Geological Survey, Conservation Division, Menlo Park, California.

Since we began with no information other than Table 3.1, a modified Kolmogorov-Smirnov test for normality with unknown means and variance was used.[12] The test required at least four bids on a tract, so that only nine bid distributions could be tested. The test was applied to each of the bid distributions, with results presented in Table 3.2. It was impossible to reject the hypothesis of log-normality at the 20 percent level in all but one of the nine tracts tested. Hence we conclude there is at least a certain structural similarity with OCS bids. One factor which could in principle affect the size of bids is the area of the tract of land offered. Bids might increase more than proportionately with the area of the tract if a minimum size tract is needed for efficient exploitation. They might increase less than proportionately if firms start to run out of money, with constant per acre bids as the size of a tract increases. We find that lot size has no effect on the size of bids.

A plot of bid per acre against lot size is given in Figure 3.1. A linear regression of bid per acre versus lot size gives a correlation coefficient, R^2, between bid per acre and acres of .00121, not significantly different from zero at the .4 level. We will return to this result to discuss the implications of independence of lot size for the structure of the market for geothermal steam. The apparent independence is used here to justify neglect of the size of the tract in all analyses of bidding, and the use of bids per acre as the fundamental data.

In two instances the BLM has offered for sale simultaneously a number of tracts located near to each other, and received a significant number of bids on each tract. On January 22, 1974, twelve tracts located in the Geysers KGRA were offered for bids, and on July 30, 1974, twelve tracts in the Roosevelt Hot Springs KGRA in Utah were offered. One obstacle to the analysis of patterns of bidding for geothermal leases is the extreme variability in quality of the geothermal resource

TABLE 3.2

KOLMOGOROV-SMIRNOV TEST

Tract	K-S Statistic	.20 sig.	.01 sig.
CA 949	.1188	.247	.348
CA 950	.4886	.265	.364
CA 951	.2890	.300	.417
CA 958	.2356	.300	.417
CA 955	.2495	.285	.405
CA 963	.1691	.285	.405
OR 12645	.2479	.300	.417
U-27391	.1575	.300	.417
U-27388	.1935	.300	.417

in different areas. It might be expected that differences in the nature of the resource, and in the knowledge which different firms possess about the resource, would swamp all other variables in explaining differences in bids. But we must be able to compare bids between tracts to infer anything about the factors which influence the size of bids.

We need, then, a number of physically similar tracts to be able to learn anything about bidding. The tracts offered in these two sales may be suitable. The test of suitability we propose is that the distributions of bids on each of the twelve tracts should be the same. That is, if the seven bids on Tract 1 at the Geysers, the six bids on Tract 2, etc., could have been drawn from the same distribution, we will conclude that there is an underlying similarity between the tracts which justifies analyzing the entire sale at the Geysers as a unit. The same procedure will be followed for the bids at Roosevelt Hot Springs.

We assume that all bid distributions are log-normal. The proposition to be tested is that all bids come from the same log-normal distribution. Any log-normal distribution can be completely described by two parameters, its mean and its variance. The mean of any distribution can be estimated as the average, or arithmetic mean, of the sample observations. The variance, a measure of the spread of the distribution, is proportional to the sum of the squared differences between each observation and the mean.

Thus, to test whether the distribution of bids per acre is the same for all tracts, we must perform two tests; a test that the variances of each distribution are identical, and a test that the means are identical. We tested first for similarity between tracts at the Geysers KGRA, and then for similarity at the Roosevelt Hot Springs KGRA. At both KGRA's we accepted the hypothesis of equality of variances. At the Geysers we accepted, and at Roosevelt Hot Springs we rejected, the hypothesis of equality of means. The tests performed were as follows. The test for equality of variance among k samples drawn from a normal population is a likelihood ratio test.[13] The test statistic is χ^2 with k-1 degrees of freedom, and is unbiased. Since eight tracts at Roosevelt Hot Springs are used, the statistic is χ^2 with 7 degrees of freedom. Its value of 5.6614 is below the fiftieth percentile of the χ^2 distribution with 7 degrees of freedom. Hence we cannot reject the hypothesis of equal variances at the .5 level.

At the Geysers we made the same test using several sets of tracts. Several alterations were made to the data at the Geysers. A tract which sold for a bid of $5.11 per acre was excluded as clearly unusual, and all bids by Edward P. Towne were ignored because of their very small size and because of the fact that two bids under that name are listed in one auction. First we used all tracts with two or more bids, except the tract with a high bid of only $5 per acre (Tract 954). This gave eleven tracts. The corrected χ^2 statistic with 10 degrees of freedom was 15.73, and we could not reject the hypothesis of equal variances at the .10 level.

Two of these eleven tracts were sold at auction held after that at which the other nine were sold, because all bids on those tracts were rejected initially by the BLM as too low. Hence the bids on these two tracts may not come from the same distribution as the rest. Excluding these two tracts gave a corrected χ^2 statistic with 8 degrees of freedom of 6.41, and we cannot reject the hypothesis of equal variances at the .5 level.

To test for equality of means we use a standard analysis of variance test, using the common sample variance estimated in the test for equality of variances.[14] The test statistic is distributed as F with k-1, n-k degrees of freedom, where n is the total number of bids. For Roosevelt Hot Springs the F statistic is 37.92. With 7, 17 degrees of freedom this is significant at the .10 level. Hence we reject the hypothesis of equality of means. At the Geysers we excluded the tracts rebid at a later auction and obtained a statistic of .8315, distributed as F with 8, 23 degrees of freedom. This falls far short of significance at the .05 level, and we cannot reject the hypothesis of equality of means.

The different properties of the bids at the two KGRA's can be explained by a physical difference between the KGRA's. At the Geysers there is a well explored, high quality field with uniform access to the underground reservoir of geothermal steam. The identical distribution of bids over tracts supports the hypothesis that bidders in the aggregate believe this to be the case, even though different bidders appear to make different estimates for specific tracts. Among oil companies which bid on the Geysers there do not appear to be any systematic differences among firms in belief about quality of the field as a whole. (See Table 3.3 on bids by bidder.) Bids and high bids vary between tracts for the same bidder. Firms not in the oil business, however, appear to make substantially lower bids.

In Roosevelt Hot Springs we observe different features. Comparing Tables 3.4 and 3.5 we observe that average variance (equal to the sum of individual variances weighted by number of bids divided by total number of bids less the number of tracts) at RHS is smaller than that at Geysers, but mean bids are much lower. Moreover, we reject the hypothesis of equal means at the .001 level. The spread is large relative to the highest bid, as compared to the relation of variance to mean bid at the Geysers. Moreover, a clear aggregate belief that tracts differ in quality is observed. Phillips appears uniformly more optimistic than other firms bidding (Table 3.1). These observations support the hypothesis that on relatively unknown fields there is differential information as to quality, since in the Geysers all oil companies appeared to behave quite similarly.

The bids for Federal leases at the Geysers thus appear to be an excellent data set for testing predictions about the influence of market structure and number of bidders on the value of a geothermal lease. We begin in Table 3.4 by pooling the bids at the Geysers to give some summary statistics on the overall distribution of bids. We can compare

TABLE 3.3

BIDS ARRANGED BY BIDDER

Tract	Bid	Bid/Acre	Acres
Shell			
1	3,200,000	1,367.52*	2,340
2	1,300,000	847.45*	1,534
			3,874
Signal			
1	1,516,660	648.14	2,340
4	28,381	281.00	101
7A	180,288	288.00	626
7B	1,087,000	1,736.42	
8	75,600	302.40*	250
9A	32,480	203.00	160
9B	192,650	1,204.06	
10	78,588	354.00*	222
11	4,770	106.00	45
12	56,666	76.88*	737
			1,209
Union			
1	774,867.60	331.14	2,340
2	1,163,953.18	758.77	1,534
3	4,707.50	26.90	175
4	48,314.36	478.36*	101
5	80,842.84	478.36*	169
6	12,243.56	5.11	2,396
7A	318,120.68	508.18	626
7B	345,000.00	565.49	
8	97,045.00	228.18	250
9A	129,161.00	807.25	160
9B	220,342.00	1,377.13*	
10	67,634.52	304.66	222
11	22,868.10	508.18*	45
12	18,631.36	52.28	737
			2,871
Occidental			
7B	335,000	535.14	626
9A	163,360	1,021.00	160
9B	220,000	1,375.00	
10	226,662	1,021.00	222

Table 3.3 continued

Tract	Bid	Bid/Acre	Acres
Thermogenics			
1	264,420	113.94	2,340
3	22,050	126.00*	175
10	27,972	126.00	222
			175
Natomas			
2	451,000	294.00	1,534
7B	2,055,000	3,282.74*	626
			626

*Winning bid.

TABLE 3.4

GEYSERS SUMMARY STATISTICS

Total of winning bids ÷ total acreage	
including rebid auctions	1,149.30
excluding rebid auctions	949.63
Unweighted average of winning bids	
including rebid auctions	896.91
excluding rebid auctions	578.56
Mean bid/acre	
including rebid auctions	547.55
excluding rebid auctions	287.28
Mean of normal distribution of logarithms (natural) of bid/acre	
including rebid auctions	5.337
excluding rebid auctions	4.866
Variance of log-normal distribution actual sample variance	
including rebid auctions	2.656
excluding rebid auctions	2.090
Estimated mean variance over tracts	
including rebid auctions	1.909
excluding rebid auctions	2.26

TABLE 3.5

MEANS AND VARIANCES BY TRACT

Geysers

Tract	Mean of logarithms	Arithmetic Mean	Variance of logarithms	# Bids
949	4.617	369	3.829	7
950	4.903	343	3.314	6
951	3.903	61	.561	4
952	5.036	262	2.331	3
953	5.144	270	2.109	2
955	7.244	1,860	.812	5
956	5.571	265	.040	2
957	7.182	1,319	.0059	3
958	5.838	415	.736	4
959	5.447	205	1.228	2
960	3.786	51	1.679	2

Table 3.5 continued

Roosevelt Hot Springs

Tract	Mean of logs	Variance of logs	# Bids
U27383	2.28	0.48	3
U27384	3.27	0.88	3
U27386	3.57	1.75	3
U27387	1.45	0.06	2
U27388	2.92	1.88	5
U27390	2.67	0.32	3
U27391	1.83	0.48	4
U12990	2.58	4.41	2

Overall mean variance = 1.19

these summary statistics with similar statistics for Federal OCS leases computed by K. C. Brown.[15] In Table 3.6 Brown gives the estimated mean variances of bids by sale for OCS oil leases. As in the case of geothermal leasing, each sale places for auction a number of individual tracts of land. Within sales, Brown accepted the hypothesis of equal variance of the bid distribution across tracts. If N_i is the number of bids on Tract k, k the number of tracts offered, and $\hat{S}_i^2$ the estimated variance on Tract i, the estimated variance is

$$\frac{\sum_i (N_i - 1)\,\hat{S}_i^2}{\sum_i N_i - k}$$

We see that the average bid on all OCS sales is very close to the average bid at the Geysers, but that the mean variance of geothermal bids at the Geysers is larger than the variance at any OCS sale. The mean variance of bids at Roosevelt Hot Springs is about the same as the OCS variances, but the average bid is much smaller. These results are about what we would expect--greater uncertainty about profits from geothermal development is reflected in the larger variance at the Geysers, and in the larger spread relative to the mean at Roosevelt Hot Springs. The results are in conformity with the prediction of Wilson's model that the underlying probability distribution of the quality of a field will be reflected in a pattern of bids with a related distribution. Bidding theory also leads us to believe that bidders will behave differently when they face stiff competition in an auction from the way they would behave with little competition.

As we would expect, the winning bid increases with the number of bidders (Figure 3.2). The average bid also increases, but more slowly. A linear regression of winning bid against number of bidders at Roosevelt Hot Springs gave a result of

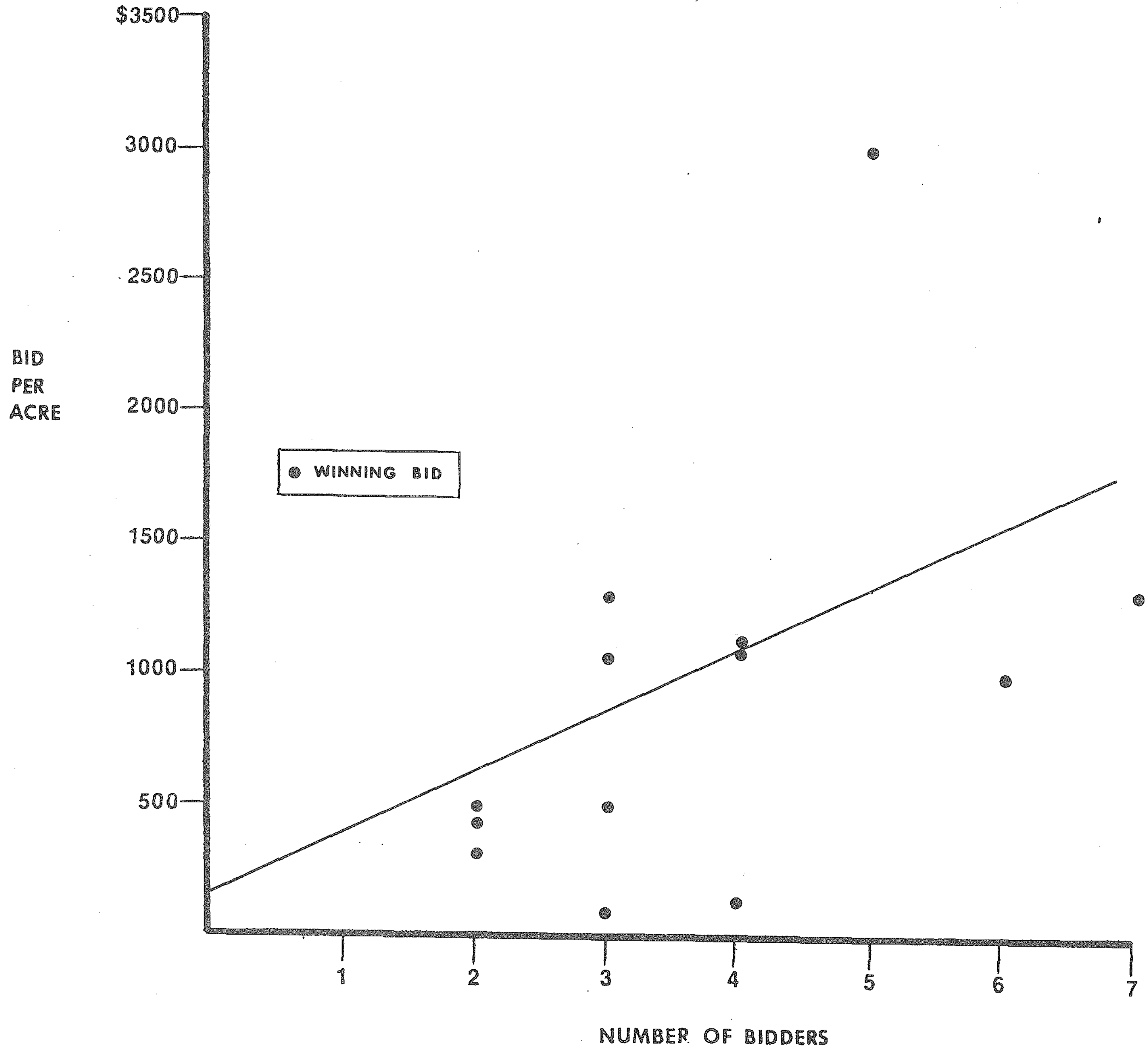
winning bid = $-$ 12.37 + 22.53 x no. of bidders
$R = .65$, $R^2 = .43$.

TABLE 3.6

BROWN'S TABLE

Sale Date	Mean Variance		Avg. Per Acre Bid
10/13/54	1.31		294
7/12/55	1.10		396
8/11/59	0.72		2,270
2/24/60	1.75		532
3/13/62	0.88		186
3/16/62	1.10		288
10/09/62	1.45		2,710
4/28/64	1.11		1,850
		Total	361

FIGURE 3.2 WINNING BID VS. NUMBER OF BIDDERS



At Geysers the same regression gave the result

$$\text{winning bid} = 139.80 + 239 \times \text{no. of bidders}$$
$$R = .49,\ R^2 = .24.$$

Regressing mean bid on number of bidders at the Geysers gives

$$\text{mean bid} = 156.54 + 94.47 \times \text{no. of bidders}$$
$$R = .31,\ R^2 = .09.$$

There are differences in strategy between firms. When we arrange bids by bidder (Figure 3.3), we discover that Signal, for example, made bids which increased with the number of bidders, while Union's bids did not. Regressing Signal's and Union's bids at the Geysers on the number of participants gives

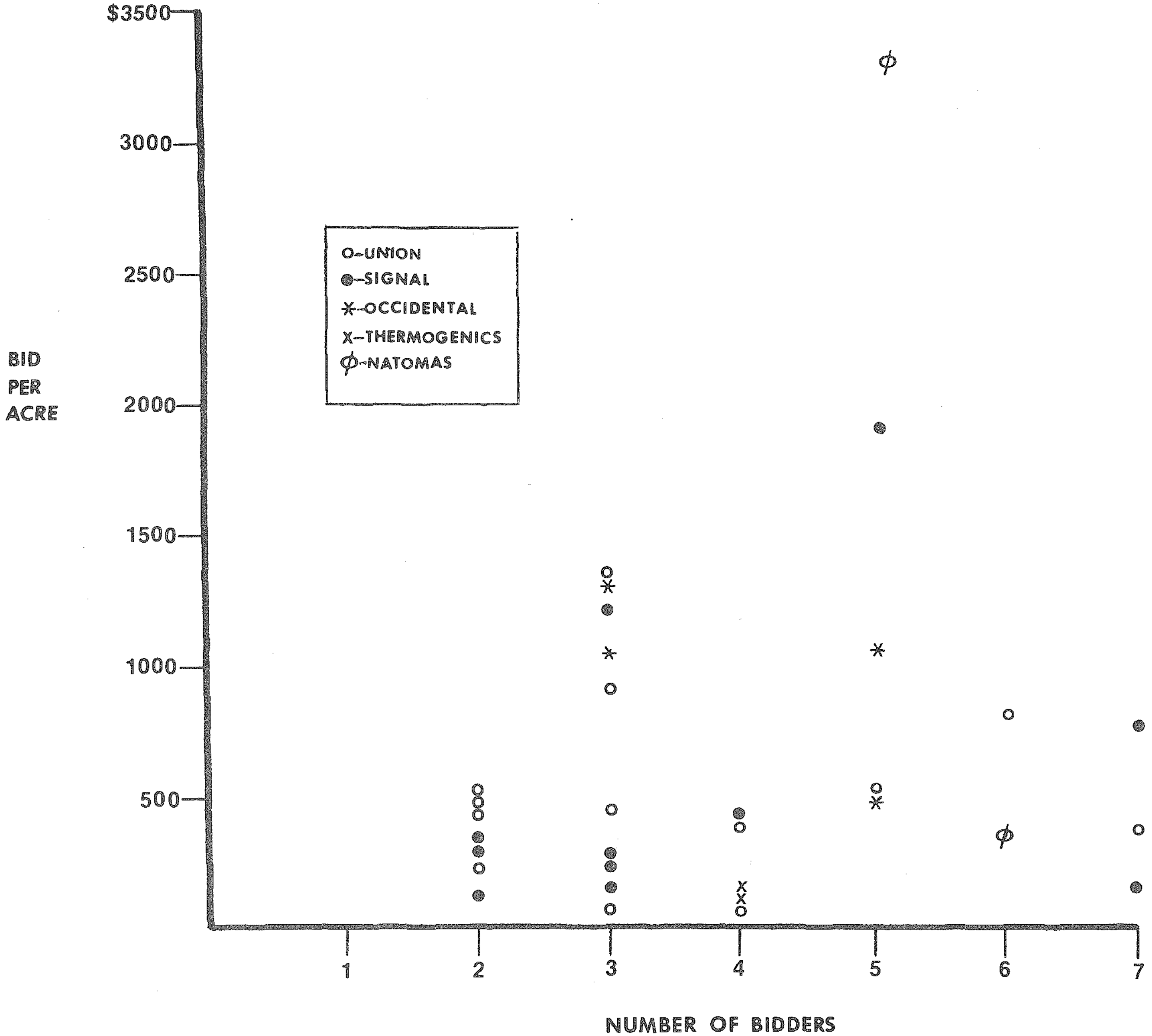
$$\text{Signal bid} = -\ 39.98 + 162.64 \times \text{no. of bidders}$$
$$R = .475,\ R^2 = .226.$$

$$\text{Union bid} = 503.64 - 3.31 \times \text{no. of bidders}$$
$$R = .015,\ R^2 = .000225.$$

We cannot tell if these differences represent effects of different information, different strategies, or other characteristics of bidders. Although the bidding data do not help in isolating the effect of these differences, we do note that oil companies are more successful than other firms. Despite the fact all participating firms are well capitalized and clearly able to bid without external financing, the single factor which explains high bids best is whether or not a firm is in the oil industry.

The mean bid/acre by major oil companies is $1,038 per acre excluding the rebid auctions; including rebid it is $1,141 per acre. These exceed the average winning bid because so many oil companies make bids close to the winner, and taking the average bid as we do weights in proportion to the number of bidders in an auction. Hence the positive correlation between average bid and number of bidders

FIGURE 3.3 INDIVIDUAL BIDS VS. NUMBER OF BIDDERS AT THE GEYSERS



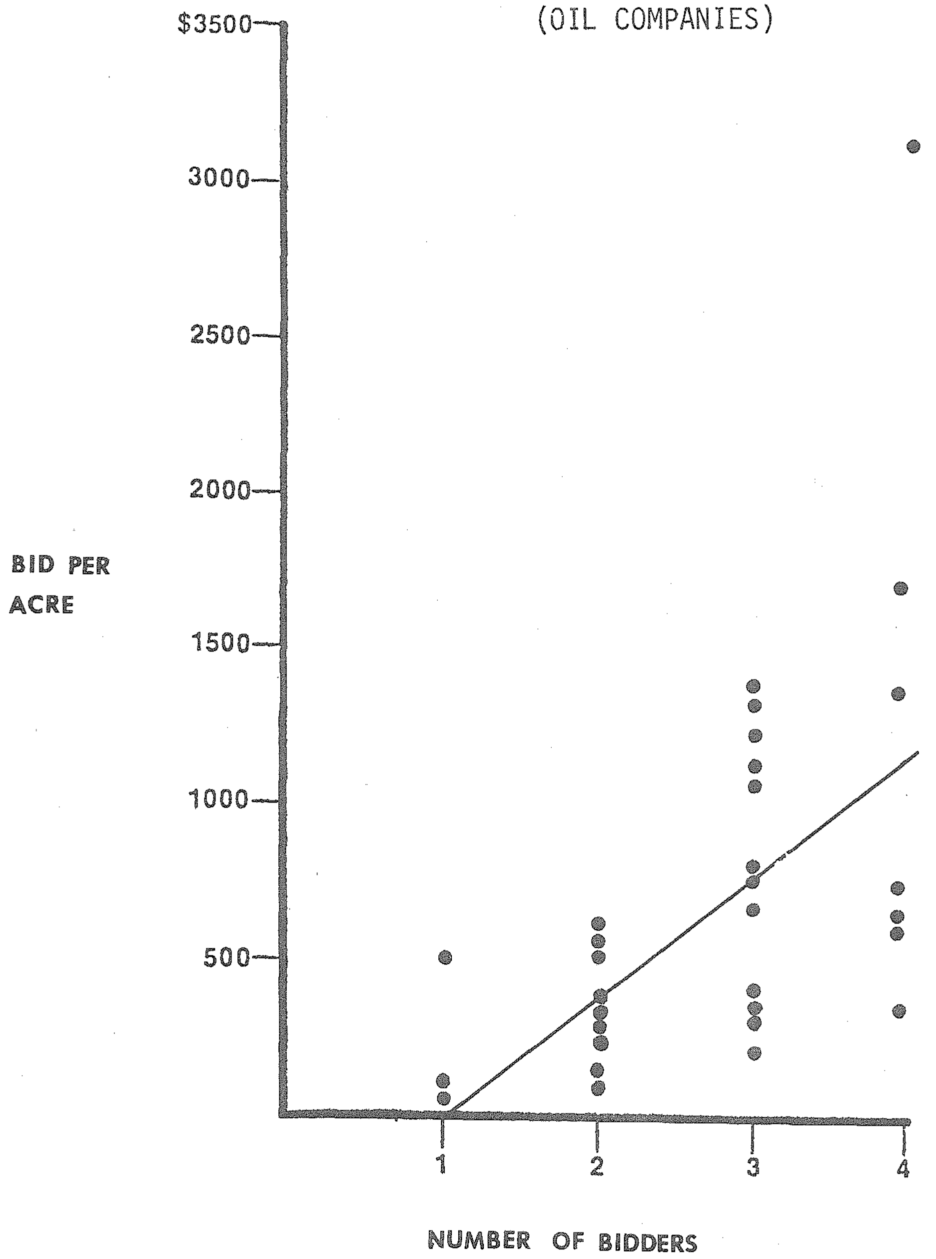
tends to overweight contested sales, which end up with high prices being paid. A linear regression of oil company bids vs. number of oil company bidders (Figure 3.4) gives the result

oil company bid = $-$ 433.67 + 404.8 x no. of oil company bidders with an $R^2 = .294$.

Other firms tend to make low bids throughout, and are more or less uniformly distributed among auctions. The positive correlation between bids and number of bidders is much higher for oil companies than for all bidders together. In theory, there are two explanations of why the size of bids and number of bidders are correlated. One explanation, which implies that increasing the number of bidders would increase the size of bids, is that when participants expect stiffer competition they bid higher. The other explanation is that both the size of bids and the number of bidders are determined by a third factor, the quality of the tract. In this case policies designed only to increase the number of bidders might not increase bids. The connection between quality of tract and the size of bids is obvious, but the connection between number of bidders and quality of tract is somewhat tenuous. For such a systematic relationship to exist, there must be a substantial fixed cost to bidding--otherwise the quality of the tract would influence only the size of the bid, not the decision to submit a bid.

The existence of these alternative explanations should, however, serve as a caution against basing leasing policy directly on assumed causal relations between the number of participants and revenues to the government. In addition it should be recognized that many other factors than those examined in the statistical analysis affect the size of bids--as is demonstrated by the rather low R^2 reported in the regression equations. Other factors which vary from tract to tract and may affect bids include grandfather rights, accessibility of the tract, stage of development of the tract, and individual corporate budget limits and objectives, including in particular the number of other tracts already won or bid on simultaneously.

FIGURE 3.4 BID PER ACRE VS. NUMBER OF BIDDERS
(OIL COMPANIES)



Footnotes to Chapter 3

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CHAPTER 4

STRUCTURE OF THE GEOTHERMAL INDUSTRY

In a previous chapter we examined some aspects of the market for electricity and market for geothermal steam from the point of view of an electric utility. In this chapter we will attempt to assess the competitive character of markets on which geothermal steam developers trade--i.e., the steam and the land market. Federal lease sales at the Geysers will form the basis of a case study of the relation between rates of return on capital and the amount paid for a lease. We will attempt to test the hypothesis that bidders are behaving as true competitors in the lease sales. Comparison of the rates of return will provide some relevant evidence. More evidence will come from the pattern of bids itself, compared with expectations derived from bidding theory.

We will then examine the outcome of the bidding process in terms of the characteristics and concentration of winning bidders, and compare the list of dominant firms with the list of dominant firms in other areas of geothermal development. Finally, we will advance several alternative explanations of the patterns which emerge, concentrating on the concept of barriers to entry.

For all firms we computed an average bid per acre at the Geysers of \$275 to \$325; for firms in the oil industry the average bid per acre was \$1,050 to \$1,150. At approximately \$300 rates of return exceed 10 percent in all but one of the cases considered in Chapter 2. When these bids were made, January 22, 1974, the existing rule on tax status was Reich, et al., which applied the percentage depletion allowance and expensing of intangible drilling cost provisions of oil and gas tax law to geothermal steam at the Geysers. Hence the relation between rate of return and lease cost derived on the basis of depletion and expensing is probably most appropriate as the basis of bidding decisions. The relation applies directly only to a firm with net revenue, exclusive of geothermal operation, larger than the amount of intangible drilling cost to be expensed. Otherwise it could not take full advantage of that provision, and the actual investment cost would increase. This would tend to make firms with inadequate taxable income from other sources bid somewhat less than large firms. However, such firms have the option of treating a drilling cost as a capital expenditure, and depreciating it over the life of the well. This approach plus percentage depletion, available to all firms, would result in rates of return reported in Chapter 2 under the heading "percentage depletion alone". When steam sells at 2.5 mills, the rate of return to the small firm when land sells at $300 per acre is about 10 percent, substantially less than the 14 percent rate of return the large firm can earn paying $1,000 per acre. The inequity in tax treatment does not alone explain the difference between oil companies and others, since a firm able to exploit depletion and expensing could earn 10 percent paying $3,000 per acre, considerably more than oil companies actually bid.

Moreover, it does not appear that aside from individuals making trivial bids <u>any</u> of the bidders are really small. A summary of characteristics of bidders is given in Table 4.1.

Relevant rates of return to compare with those on geothermal development are given in Table 4.2. They are the ratio of after-tax profits to stockholders' equity in various industries. Since some leverage exists in all firms' financial structures, these are probably overestimates of average rates of return to capital invested. Moreover, marginal rates of return on investment--the relevant measures with which to compare geothermal rates of return--are presumably smaller than the average. Hence, if geothermal energy offers an average rate of return above those tabulated, it is almost certainly a desirable investment.

TABLE 4.1

BIDDERS ON GEOTHERMAL LEASES

Major Oil Companies

Union
Shell
Chevron (Standard of California)
Getty
Gulf
Phillips

Other Oil Companies

Occidental
Signal, acquired by Burmah in February, 1974, which is currently trying to dispose of its U.S. assets
Natomas, 600 employees, 380 M assets, which acquired Thermal for $20 M
Al Aquitane, 315 employess, subsidiary of Aquitane of Canada, assets over $200 M

Other Large Firms

Dow Chemical
LVO Corporation of Tulsa, an energy related company with $39.3 million sales and 1,126 employees in 1974
Southern Union Production Company, with sales of $13 M and 110 employees -- a subsidiary of Southern Union Gas, with sales of $131 M and 2,200 employees

Publicly Owned Utilities

City of Santa Clara
Northern California Power Agency

Geothermal Developers

Magma -- Magma Power Co. has assets of $16 M, Magma Energy $3.5 M
Geothermal Resources International -- $5-6 M sales and 9 employees(?)
California Geothermal -- unable to find any information on assets
Thermogenics -- tangible assets over $1 M. Bid total of $506,000 at various auctions
Republic Geothermal -- reportedly well financed -- bid and won leases totalling $1,157,000

Others - no information available

American Oil Shale
Hydro-Search

Source: Moody's Industrial and OTC Industrial Newsletter

TABLE 4.2

RATIO OF PROFITS AFTER TAXES TO STOCKHOLDERS EQUITY
(Percent)

Year	All Manufacturing ERP estimate	All Manufacturing FNCB estimate	Petroleum & Coal
1970	9.3	10.1	10.9
1971	9.7	10.8	11.2
1972	10.6	12.1	10.8
1973	12.8	14.8	15.6
1974*	15.5		23.2

*Third quarter only. This is a new series calculated on a different basis than earlier years. On this basis rate of return for all manufacturing 1973 (fourth quarter) is 14.3% for oil and coal 17.0%.

Source: Economic Report of the President, except FNCB and 1970-73 petroleum rates of return, from "Competition in the Oil Industry," published by Exxon.

We note first that the 20 percent rate of return earned by oil companies in 1975 cannot be achieved when steam sells at 2.5 mills, even if land is free (Table 2.3). If the utility buying steam is held to a 10 percent rate of return and all economic rents are passed back to the geothermal developer, with depletion and expensing he can earn over 20 percent rate of return paying $3,000 per acre when electricity sells for 6 mills/kwh (Table 2.5). This appears to be the situation in regard to the price of steam in 1974. Hence at a 20 percent rate of return the value of a lease will vary with market power in selling steam from 0 to $3,000 per acre.

A 12 percent rate of return, characteristic of the oil industry before 1973 and of other industries, would justify a bid of about $1,000 per acre under the tax treatment accorded the Geysers in 1974, even at a 2.5 mill steam price (Table 2.3). This lower rate of return is not unrealistic since the 20 percent nominal rates earned in 1974 occurred in a period of high inflation which would make real rates of return substantially lower than nominal rates. Since we have included no inflation of costs or revenues in our calculations in Chapter 2, the rates of return as a function of lease cost are estimated as <u>real</u> rates of return. Moreover, even in 1974 the rate of return on Aaa corporate bonds never exceeded 9.27 percent. Since this source of financing is available to major oil companies, even a risky investment offering a 12 percent rate of return would appear profitable. If a real rate of return of 12 percent were adequate, the 1974 price of steam (4 mills) would justify a bid of almost $10,000 per acre (Table 2.5).

At rates of return appropriate to the oil industry, their average bid for land at the Geysers falls between the minimum bid we would expect with competitive bidding for land and a monopsonistic buyer of steam and the maximum bid which would be justified if steam developers could capture from the utility large parts of the economic rent accruing to geothermal energy. Bids are in fact far below that maximum. At rates of return characteristic of corporate bond yields (under 10 percent), bids per acre are below the value of a lease under the most unfavorable assumption about the price of steam, unless bidders do not expect favorable tax treatment.

Three factors would tend to justify bids below the minimum we calculate. One is the delay because of environmental considerations or simply the time required to construct power stations, between lease acquisition and beginning of production. A second is the possibility of reselling a lease, which makes it unnecessary to be high bidder to obtain the desired property eventually. Third, the small number of bidders will, according to bidding theory, keep both the average and winning bids down even in the absence of collusion. This is an effect of small numbers, since even without collusion small numbers can cause behavior to differ from the competitive norm. On the basis of relation between rates of return and lease cost alone, we cannot reject the hypothesis of competition in the market for leases with the qualification that it is almost certainly "competition among the few". On the other hand, we also cannot reject the hypothesis that developers obtain large earnings selling steam and succeed in limiting competition for leases, so that the price of land remains low. We must examine additional data to find evidence to distinguish between these hypotheses.

There is a clear division in bidding practice between oil companies and other bidders. The fact that the average bid by oil companies exceeds the average winning bid, and that the bid increases with the number of competitors, is consistent with the idea that oil companies compete vigorously with each other in acquiring leases. An alternative explanation, that oil companies are bidding up leases in order to keep others out of the geothermal industry is clearly false. Other barriers to entry may exist, but the fact that oil company bids appear low at reasonable rates of return is clear evidence that no such explanation is needed. Indeed, winning bids are not so high relative to potential earnings that any investor able to raise sufficient capital and assemble a drilling and exploration team would be deterred from entering the field. To find barriers to entry we must look for difficulties in those two areas.

Examination of standard measures of concentration of the geothermal industry reveals a potentially more disturbing pattern. We now examine the entire Federal competitive leasing program, including all fields leased up to December 1974. Table 4.3 gives the share of average and total expenditure of all firms which won any acreage at all in the auction. In Table 4.4 the names in order of rank of the top eight firms in each category and the share of the top four and top eight in each category are listed.

Since these auctions took place, Thermal Power Co., an operating company in a joint venture with Magma at the Geysers, has been absorbed by Natomas.

The share of expenditure is probably a better measure of concentration than the share of acreage, since it weights physical quantities by a market-determined estimate of their value. However, calculated concentration ratios are about the same under both definitions.

This is fortunate, since leased Federal lands form only a small fraction of total geothermal acreage, and we only have data on acreage in other areas. We have not undertaken the major research project of determining the share of top firms in all areas of geothermal activity, but three increments to Federal leasing data suggest a pattern. In Tables 4.5-4.7 we present data on acreage and share of various firms in the Imperial Valley, the Geysers area, and on California state lands. Of the four firms (or groups of firms) which hold an estimated 75 percent of the geothermal land in the Imperial Valley, three appear in the top eight of Federal acreage share, and the fourth is a group including one of the top eight. At the Geysers two of the four listed appear in

TABLE 4.3

FEDERAL LEASES

Company	Acreage Won*	Share of Acreage	Rank	Amt. Spent**	Share of Spending	Rank
Union	5,431	.06570	7	$ 498,290.10	.0460	6
Shell	3,874	.04748	8	4,500,000	.4151	1
Signal	987	.01209		188,932	.0174	8
Thermo	175	.00214		22,050	.0020	
GRI	1,772	.02172		14,000	.0013	
Chevron	15,904	.19495	2	970,498	.0895	4
Natomas	5,699	.06985	6	2,143,912	.1978	2
Occidental	222	.00272		226,662	.0209	
Getty	13,753	.16858	3	273,798	.0253	7
Republic	7,265	.08905	5	1,171,333	.1080	3
Magma	7,626	.09348	4	17,391	.0016	
Phillips	18,870	.23131	1	813,867.61	.0750	5
Hydro-Search	2,401	.02943		15,108	.0014	

*Total acreage - 81,578

**Total spent - $10,840,736.12

TABLE 4.4

FEDERAL LEASES

Acreage Share	Spending Share
Phillips	Shell
Chevron (Standard)	Natomas
Getty	Republic
Magma	Chevron
Republic	Phillips
Natomas	Union
Union	Getty
Shell	Signal
4-firm concentration ratio	4-firm concentration ratio
.688	.810
8-firm concentration ratio	8-firm concentration ratio
.961	.974

TABLE 4.5

SALTON SEA

Company	Leases	Acreage	Share
Union	136	28,620	.200
Standard (Chevron)	124	18,600	.130
Magma	60	21,000	.147
SP Land		37,000	.258
(Assigned from Arco & Imperial, shared with Phillips & SCE)			
Total of Top 4		105,220	.734
15 other		38,060	
TOTAL		143,280	

Source: Michael Sullivan, Steven McDougal, F. V. Huntley, "Patterns of Geothermal Lease Acquisition in the Imperial Valley, 1958-1974," University of California, Riverside, August, 1974.

TABLE 4.6

GEYSERS AREA - 1969

Signal	25,000 acres
Magma-Thermal	6,500 acres
GRI	1,680 acres
Union	9,000 acres
Occidental?	

Source: D. A. McMillan, Jr., "Economics of the Geysers Geothermal Field, California," Geothermics, Vol. 2, Part 2, 1705-1714.

TABLE 4.7

CALIFORNIA STATE LANDS

	Company	Acreage
Leases	Union	4,000

Permits to Explore

Company	Acreage	Share of Total
Arco	3,900	.075
Getty	24,595	.470
Gulf	14,918	.285
American-Thermal	8,898	.170

Source: California State Lands Commission, "Geothermal Operations and Leasing Procedures," March 14, 1975.

the top eight of Federal lands on both lists, and an additional firm (Signal) appears in the top eight of expenditure share. Union holds the only actual leases on California state lands, but the free exploration permits at least indicate interest, and the firms holding those permits include one of the Federal top eight. Arco did not bid on Federal leases, and Gulf bid unsuccessfully many times. If we pool all the acreage on which we have information, we have Table 4.8, of acreage and share in all these areas. The table has no particular interest save as an indication that the pattern of concentration on Federal lands is not immediately proved to be atypical by considering other areas.

Hence we return to discuss concentration at the Geysers as a subject of potential interest. It clearly arises from the large difference between average bids by oil companies and by others. We have seen that this difference cannot be a result of predatory actions to exclude competitors, since average oil company bids do not exceed conservative estimates of the value of a lease. Part of the difference may be due to the inability of small firms to capture the advantages of depletion and expensing, and without those advantages the investment looks much less desirable. A test of this theory can be made when another lease sale at the Geysers takes place. The removal of the depletion allowance for large firms but not for those producing less than 2,000 barrels of oil per day should decrease the value of a lease to major oil companies while keeping it the same for small. On the other hand, expensing of intangible drilling costs remains on the books, so that small firms remain at a disadvantage. Hence, if there is a taxation effect, it should reveal itself in significantly lower bids by major oil companies at the next auction, similar bids by small companies still entitled to depletion, and little difference in bids between the groups. These results are predicted by the fact that the graph of rate of return vs. lease cost under expensing almost coincides with that under depletion alone.

TABLE 4.8

RANKING OF FIRMS WITH GEOTHERMAL
LEASES IN CALIFORNIA

Name	Rank	Share
Phillips	1	.148
Union	2	.125
Getty	3	.102
Magma	4	.093
Chevron	5	.090
Signal	6	.069
Gulf	7	.040
American-Thermal	8	.024
Republic	9	.019
Natomas	10	.015
Shell	11	.010
GRI	12	.007
Occidental	13	.0006

Control of Acreage

4-firm	.468
8-firm	.691
12-firm	.742

The magnitude of the difference in bids between the small number of firms which dominate lease sales and the others suggests that there is no active collusion among those bidders to keep their lease payments as low as possible--i.e., just high enough to prevent others from participating in their high rates of return. But, to explain why they can bid low enough to obtain high rates of return, we must find some other barriers to entry. By barriers to entry we mean technical or institutional aspects of an industry which make it difficult for new firms to compete successfully in some market with established firms (Table 4.9).

Capital market imperfections appear to limit geothermal development to companies which can raise funds internally. This is also the case of oil exploration. At a theoretical level default risk may be cited as the source of these imperfections. Practically we observe an unwillingness of banks to lend for this purpose. Moreover, the California Commissioner of Corporations in 1974 ruled that stock issues to finance geothermal exploration were excessively speculative, and closed off that source of funds.

The phenomenon of default risk is worth exploring in detail. The geothermal resource is characterized by uncertainty regarding future net revenues from any tract of land. The price of leases at the best fields is sufficiently high that there is substantial risk that small firms will default on the loans used to finance purchase of leases.

Default risk arises because of the progressively reduced uncertainty associated with the field. If it becomes obvious that rents will never cover the payments--of a loan or as royalties--the developer will find it in his interest to default if his equity is sufficiently small. This does not destroy the resource, but it does distort the incentives perceived by participants in the competitive bidding. Losses are limited to the equity of the defaulting corporation. By truncating possible losses in the event of complete failure, this limitation of

TABLE 4.9

SUMMARY OF POSSIBLE ENTRY RESTRICTIONS

1. Default risk-difficulty of bank financing

2. Commissioner of Corporations restricts equity financing

3. Tax advantages different for Geysers and other fields, different between firms

4. Capital rationing within firms and increasing PV with slower development

5. Diversification and risk aversion

liability makes the expected value of net returns larger to a small firm than it is to a firm with equity large enough to cover all losses. Banks, however, are perfectly aware of this possibility. One consequence is that default risk can lead banks to ration capital--that is, to refuse to lend more than a certain amount, depending on the other assets of the borrower, at any rate of interest. This rationing could itself form a barrier to entry requiring some minimum equity to allow participation.

The system of bonus bids places an additional capital requirement on developers over and above the amount needed for exploration and drilling. This cannot alone account for the lack of success of small bidders, since in all the other areas we have examined leases are on a pure royalty basis, requiring no initial investment, and yet concentration is not substantially different. The real capital requirement which appears to make capital market imperfections a barrier to entry is that for drilling. At a cost of $350,000 per well, requiring 40 acres of land at about $1,000 per acre, drilling cost is almost ten times leasing cost.

There is another way in which restricted access to capital markets can form a barrier to entry even if smaller firms can raise enough equity capital to invest in drilling on an efficient scale. A firm which can sell bonds which qualify for an Aaa rating, for example by borrowing to finance a safe, unrelated investment such as refinery construction, can free up funds internally for investment in geothermal development. If, for example, half the capital invested in geothermal is raised in this fashion, the actual rate of return on equity will be computed as follows. Each year the firm's gross revenue and costs will be the same as for 100 percent equity financing; an additional cost equal to the interest payments on bonds will be incurred. If bonds have the same 20 year life as the revenue stream, and if the interest on bonds is 9 percent, each year's net revenue will exceed 50 percent of the net revenue calculated on the assumption of 100 percent equity financing as long as the rate of return with 100 percent equity financing exceeds 9 percent. Since equity capital forms only half of the investment, the rate of return on equity is increased by access to debt financing. In Table 4.10 we compute actual rates of return on equity, assuming debt-equity ratio equal to 1, 9 percent intrest on bonds, and the tax treatment of depletion and expensing, and a 2.5 mill price of steam.

In Table 4.10 we observe substantial increases in the rate of return on equity as long as the rates of return on investment exceed the bond rate. Since access to bond markets is restricted to large firms with activities outside the geothermal field, these rates of return help explain the high bids of such firms. This barrier compares in magnitude and nature to those found in oil exploration and production, yet in that industry there are 16 major integrated producers and hundreds of small operators.

Finally, firms with restricted access to external capital markets and limited assets may not behave in accordance with one of the assumptions made earlier with regard to bidding behavior--neutrality toward risk. One reviewer of a draft of this report put the point very well in arguing that the distinction between "oil companies" and others is inappropriate: "The real distinction should be, however, organizations with large financial resources. The former, in this case being oil companies, can minimize risk preference considerations and essentially just play the odds with respect to both winning the lease and the economic consequences thereof. By contrast, the organizations with more limited resources can afford the mistake of bidding too low and not winning the lease, but cannot afford the mistake of bidding too much and leaving money on the table. The limited resource organization must also limit its total exposure which means bidding on fewer leases or bidding less on leases of interest. For these and other reasons they bid more conservatively."

TABLE 4.10

RATES OF RETURN ON EQUITY WITH
DEPLETION AND EXPENSING

Lease Cost ($)	Rate of Return on Equity with 50% Debt Financing	Rate of Return with 100% Equity
-0-	30	16.8
1,000	24	13.9
3,000	16	9.8
5,000	9	7.0
10,000	4.5	2.5

At OCS lease sales the eight-firm concentration ratios have been as in Table 4.11, all but one of which are lower than the four-firm concentration ratio at the Geysers. In production oil industry concentration ratios are even lower. These and other concentration ratios in related energy fields are given in Table 4.11.

The lack of correlation between bids per acre and the size of a tract found in Chapter 2 suggests that the barrier to entry operates at an even lower level than one well. If it is difficult to raise debt capital, large tracts will be less desirable to firms unable to finance bonus payments internally since they will strain capital availability. We might expect that bids/acre by non-oil companies, or the number of bidders, would fall off as tracts get larger, yet this is not the case. We might also expect oil companies to bid more on larger tracts since they could then be in a position to construct an integrated operation and capture rents which now stop at the electric utility. That this is not the case is not completely explained by the absolute barrier to entry into generation. With a field large enough to run a minimum efficient scale plant, a developer could contract with a new utility, such as NCPA, to build a power station, as long as PG&E or other preexisting utilities could be made to wheel power. Perhaps these potential competitors make it necessary for PG&E to pass on a substantial part of its "rents". If such is the case, the rate of return to be expected by developers will rise to that predicted under integrated operation at current lease sale prices.

Another explanation of the independence of bids/acre and tract size involves another possible barrier to entry, a shortage of the skills and personnel for geothermal exploration and development. If we expect resources to go in general to the highest bidder, the shortage would only be a barrier to small firms because of the expenditure needed to hire a team away from its current employer. If we add, however, the assumption that exploration and drilling teams are indivisible and must be of a certain minimum size, a real barrier exists.

TABLE 4.11

EIGHT-FIRM CONCENTRATION RATIOS - OCS

Date	Ratio
10/54	67%
11/54	68
7/55	62
2/60	45
3/62	61
6/67	53
2/68	84
5/68	33
12/70	29
9/72	53
12/72	32
6/73	16
12/73	74
3/74	49
5/74	40

CONCENTRATION RATIOS

Area	4-firm	8-firm
Oil production	31	50
Gas production	31	46
Coal production	29	39
Uranium mill output	55	78
Uranium reserves	57	
Geothermal leasing	47	69

Source: Exxon, "Competition in the Oil Industry"

By itself that indivisibility would not give established firms an advantage over new entrants. If, however, it requires either a large geothermal operation or other activities to keep a team employed, and if there is uncertainty about the ability to obtain them on a part-time basis when needed, large firms with such teams would have an advantage over small rivals.

A small holding of land might then be worthless because of the difficulty of obtaining the skills necessary to work it, while a large holding would require a prohibitive amount of capital to obtain.

CHAPTER 5

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Conclusions

Six major conclusions follow from our investigation of the economics of geothermal leasing and development.

1. Even at high rates of return on alternative investments, bids per acre for Federal leases in the Geysers field were less under tax laws prevailing when the auction was held than they would be if all markets, including that on which electricity is sold, were perfectly competitive.

2. Oil companies bid significantly more per acre than the average of all bids, and this difference is larger than can be explained by tax advantages accruing to large firms, especially since oil companies appear to have more profitable alternative investment opportunities than do other firms.

3. There is evidence suggesting that the geothermal industry is very concentrated.

4. There is evidence consistent with the belief that oil companies compete to some degree with each other for leases, but the competition is not perfect.

5. There may be substantial barriers to entry in the geothermal field.

6. We cannot tell who is receiving the bulk of the economic rent inhering in the geothermal resource, but qualitatively it is apparently shared by landowners, developers, and either or both utilities and consumers. That is, landowners should be willing to accept lower lease

prices, developers should be willing to pay more for leases, and utilities pay more for steam without hindering the development of the resource.

5.2 Recommendations for Further Research

1. The manner in which electric utilities are regulated has important effects on their demand for geothermal steam, and consequently on the incentives and returns facing geothermal developers. Research is needed on the effects of current regulatory practice and on the impact of changes in regulation, particularly with regard to rate structure, allowing utilities to drill for steam, and allowing new entry into electricity generation. Even though Averch-Johnson models of the effects of regulation are much in vogue, projects which propose alternative theories of regulation should be encouraged.

2. There is enough evidence that concentration and barriers to entry characterize the geothermal development industry that substantial research on barriers to entry, and on the general assessment of the degree of competition in geothermal development, is justified.

3. Theoretical modelling and empirical study of the competitive bidding process for geothermal leases and for the related Outer Continental Shelf oil leases should be supported. Research directed at obtaining quantitative estimates of the reduction in bids resulting from small numbers of bidders and uncertainty about the quality of lease tracts should be particularly encouraged.

4. In OCS bidding a clear difference in bids between "wildcat" tracts and tracts contiguous to wells already in production has been observed. Research attempting to identify the effects of asymmetric information on the pattern of geothermal bids is also needed.

5. The straightforward task of estimating the cost of finding steam and producing electricity under varying conditions must be pursued vigorously, as the basis for all definitive economic analysis.